# FY17 RWDC National Unmanned Aircraft System (UAS) Challenge: Farmer's Companion

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All team members have filled out the surveys.
The team's objective function is: 0.7536.



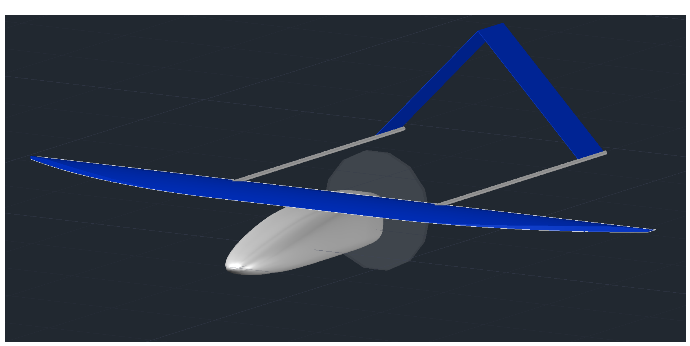

Figure 1: Final Design

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# Abstract

With an estimated additional two billion people on Earth by 2050, a food crisis is bound to emerge. As proposed in the FY17 Real World Design Challenge, the team has taken on the task of designing an unmanned aircraft system that can utilize current technology to be a multipurpose tool for farmers. This document presents a solution to the challenge. The Andover Blueprints focused on four aspects of the challenge: payload, endurance, speed, and safety. The logistics, survey, and dash missions test these first three aspects respectively. The national challenge solely focuses on the last aspect. During the challenge, the Andover Blueprints created an ideal solution within the greater United States, and focused on a commonly produced crop: corn.

The team's research suggests that the strongest candidate for a multiuse UAS airframe is a fixed wing pusher plane, designed and built using determined specifications. Creating an airframe from the ground up cuts costs, increases efficiency, and widens the capabilities of the plane for the product specifically. When equipped with a 55CC gas engine, the aircraft is capable of executing each mission with the highest degree of reliability and precision, while offering the variability required for the additional agricultural and commercial applications.

In the logistics mission, the UAV flies one mile under autopilot with a new center pivot irrigation motor and returns with the broken motor. As for the survey mission, the plane flies for over 7 hours while covering 25 square miles. The purpose of the mission is to scan for crop health with the Sequoia multispectral sensor. For the dash mission, the UAV flies 1 mile and back while utilizing the sensor to scan for crop streaking. The logistics and survey missions use a GoPro HERO5 Session camera to film, and the dash mission uses the camera to scan.

The additional agricultural missions include scanning for moisture detection, infestation detection, creation of variable-rate applicability and reflectance maps, biomass detection, and more. All follow a similar layout to the survey mission and carry the same payload. The additional commercial applications include pollution monitoring, structural scanning, monitoring of electrical lines and oil pipelines, and more. The team's UAS is extremely versatile, so farmers and other customers have an incentive to purchase it.

Following a scanning mission conducted by the UAV, the raw data from the cameras and sensors is sent to the Andover Blueprints' corporate headquarters. There, professionals analyze the readings and convert it to useful data and suggestions for a farmer as part of a monthly subscription service. The system is sold with a yearly insurance plan that allows farmers to return the UAS for a nominal fee, after which the system is quickly fixed and returned. The UAS is designed as a package to be a full, complete, and cost effective tool for the farmer.

The team also recognizes that safety is a crucial aspect of modern day UAS's, so the team implemented extensive preflight 3D mapping, landing and takeoff system assurance, a preflight check, and an obstacle avoidance system.

# Chapter 1

# Team Engagement

## 1.1 Team Formation and Project Operation

Right from the beginning, there was a lot of thought and consideration as to who should be on the 2016-2017 RWDC Andover Team. The first step was recruiting members with varying skill levels in STEM. As a team of six people, the team was able to maximize everyone's skill levels by assigning roles for all. Since this was a very detailed project, it took different types of people and their personalities. By doing this, the team knew that it would be successful. This is even true in the real world. In terms of leadership, Kunal took the role of general project manager, and he worked to help coordinate this project from start to finish. Kunal had previous experience in STEM from First Lego League (FLL), various summer camps, and leadership experience from leading other STEM projects. Alex had experience in flying RC drones, various summer camps, and robotics competitions. Vishvesh (Vish) had experience flying drones and in robotics and using simulators and RC drones. Alex and Vish took on the roles of technological and design managers for the entire project and lead the creation of missions and the selection of system components to make the UAS function in a real life situation. With Alex's and Vish's knowledge, the team was able to identify the purpose of each of the three minimum-requirement missions (logistics, dash, and survey) and the expected payloads for each of those missions. The team used their knowledge to help determine the sensors, C3 equipment, and support equipment needed, not only for the three minimum-requirement missions, but also for the additional missions developed. Ruide (also written as Reader) brought his experience in flying drones and RC models, as well as his 3D modeling knowledge, to the team. As a result, he helped in a variety of tasks, including designing and creating both the UAV and flight plans, performing all of the analysis necessary for the UAV, and assisting Alex and Vish with the development of missions. Ruide also worked together to develop the 3D CAD model of the UAV. Stephen (Steve) was really interested in the business aspect of the challenge, so he helped the team with creating business plans for the missions, figuring out a strategy to make the most profit, and marketing. Sebastian had prior experience in a competition similar to RWDC, called The Tech Challenge (TC). He developed the missions alongside Vish and Alex, led the design of the survey mission, and worked to format the engineering notebook properly with prior experience from TC.

After the state competition, the team wished to promote women in STEM. So the members started the "Shadow" program, which allows anyone, with or without a STEM background, to participate in the team's meetings. For example, one of the shadow-ees, Saniya Singh, provided us with her valuable opinions regarding this notebook.

## 1.2 Acquiring and Engaging Mentors

The team primarily contacted and worked with four mentors, Sebastian's uncle, Mr. Frankel, a fellow student, a patent lawyer from Covington and Burling, and Vish's grandfather. The team contacted Mr. Jeff Coppola with questions regarding the rules, and Mr. Frankel provided us with a significant amount of information concerning farming. He works a variety of jobs, including raising livestock and working on a farm. For example, he raised a large flock of sheep on a ranch recently in Napa, California. This made him an excellent resource when the team researched the options for the dash mission.

A fellow Phillips Academy student, Eli Newell, also provided the team with valuable information on agriculture and livestock. Mr. Newell is employed on a small farm during breaks and the summer. His experience in agriculture came to the team's attention as he began to push for a more aggressive farming program at Phillips Academy. He manages the finances & taxes and works in the fields on a daily basis when not attending school. Therefore, he was able to offer the team key information on developing all agricultural-related missions.

Sebastian's father works at a law firm called Covington and Burling, and he was able to contact a colleague, so the team could discuss patent law and the process and requirements for filing a patent. The lawyer, Mr. Winslow Taub, provided the team with pro bono assistance and helped the team understand patents, including the process of submitting specifications and claims. This allowed the team to construct an accurate and effective patent section.

Vish's grandfather, Dr. Omkar Nath Dhar, is an agricultural consultant and farmer in India. He provided valuable insight into the needs of farmers and gave the team different ideas that a company would be most efficient in helping a farmer. Dr. Dhar also helped the team understand how a farmer deals with infestation.

In addition to these agricultural mentors, the team contacted farms in Massachusetts by phone about what they would like to see in an agricultural UAV and whether they would buy the service for a given price. The team also paid a visit to Smolak Farms in North Andover.

## 1.3 State the Project Goal

Many companies have recently started to experiment with UAS's, given the potential applications that they can provide. Considering the enumerable uses of a UAS for a farmer, a UAV must be designed with various "missions" in mind. Due to the upcoming possibility of serious food shortages as population increases, a drone that provides farmers with solutions to many of their simple issues is essential. In order to clarify the variety of uses for a farm based UAS, as said in the challenge document, three categories are created: the logistics mission, the survey mission, and the dash mission. The logistics mission is about transferring a package ten pounds or heavier over a distance of one mile and then back. This allows farmers to transport heavy items like center pivot irrigation replacement motors to specific areas of the field. The survey mission is about surveying an area greater than or equal to 0.25 miles. This allows a farmer to scan plants in a field for things like crop health. Finally, the dash mission is about traveling a distance of 1 mile at the fastest speed. This allows farmers to do things like determining the status of irrigation systems in the field. Furthermore, the UAS must be capable of completing additional agricultural missions, to assist the farmer. Example additional agricultural missions include determining the moisture content of the crops, monitoring irrigation, biomass, infestation, and more. Finally, the system should have additional commercial applications, such as monitoring and assisting in oil spills, ground and water pollution containment, and more. As said in the challenge document, the objective function is a mathematical way to quantify the effectiveness of the solution.

$$
Maximize\left\{ mean \left\{ \begin{array}{c} f_1 = \dfrac{W_p^2}{W_p^2 + 100} \\ f_2 = \dfrac{T_f}{T_f + 45} \\ f_3 = \dfrac{V_c^{0.5}}{87^{0.5}} \\ f_4 = \dfrac{N_m^{1.5}}{N_m^{1.5} + 5^{1.5}} \\ f_5 = \left(\dfrac{TR_{Year5} - E_{Year5}}{TR_{Year5}}\right) \end{array} \right\} \right\}
$$

Figure 2: Objective Function

The team had to be able to design an unmanned aerial system that can demonstrate an efficient way to complete each of the logistics, survey, and dash missions. The logistics mission ($\frac{W_p^2}{W_p^2+100}$) allowed us to quantify how effective the total payload weight was. The team needed to show that the heaviest possible payload weight was used for the payload. The significance of this is to show that the UAV can handle heavy payloads without a detrimental change in performance.

The survey mission ($\frac{T_f}{T_f+45}$) allowed the group to quantify the endurance of the UAV. The team needed to show that the UAV with the largest endurance was used. Since endurance is calculated based on how much fuel is onboard, the team decided to calculate the maximum possible fuel weight to get the highest endurance. To do this, the team took the maximum possible payload weight (because of the FAA restrictions, it must be 55 lbs), subtracted all of the weights of the necessary equipment needed onboard, and then calculated the remaining space for fuel. The significance of this mission is to show that the UAV can stay in flight for a considerable amount of time, in case of mid-flight emergencies during a particular mission, or if a farmer wants to check an additional thing while the UAV is in flight.

The dash mission ($\frac{V_c^{0.5}}{87^{0.5}}$) allowed us to quantify the speed of the UAV. The team needed to show that the UAV could go at the fastest speed. In this challenge, the maximum speed was set at 87 knots due to FAA regulations. Therefore, while designing the UAV, the team aimed for a maximum speed of 87 knots. The significance of this mission is to show that the UAV can perform its missions quickly and efficiently.

The additional missions ($\frac{N_m^{1.5}}{N_m^{1.5}+5^{1.5}}$) allowed us to showcase the unique missions that the UAV could perform. The team needed to show that the team's UAV could perform multiple distinct missions. The team researched present-day uses for drones and found articles that listed many distinct uses. Then the team debated whether each use was possible with the team's UAV and came up with a lengthy list of approved uses. The significance of this is for the UAV to be able to be deployed for a diverse portfolio of missions, thus showing that the team's UAV is a multipurpose tool suitable for actual customers in the market.

Maximizing business profitability ($\frac{TR_{Year5}-OE_{Year5}}{TR_{Year5}}$) had the team minimize operational expenses to increase the team's overall profitability. The variable, $TR_{Year5}$ , represents the total income received from running the business over a 5-year period, and the variable, $E_{Year5}$ , represents the operating expense over a 5-year period. All of this was done by carefully selecting operational personnel and consumables and choosing an appropriate selling cost that was competitive in the market. The significance of this is to show that the team's UAV can help create a viable business and to demonstrate that the UAV is competitive in the market.

Ideally, the solution should reach an objective function approaching one, but because the maximum value for the business case is .20 for the business case (due to the 25% profit cap) the highest possible value is .84. The team's solution is 0.7536.

## 1.4 Tool Set-up / Learning / Validation

Right from the beginning of the competition, the team decided to use Google Drive instead of Windchill because Google Drive made it easier for everyone to collaborate and share things with one another, and everyone was familiar with Google Drive. Also, the members lived in different time zones in and outside the US, and it was very difficult to communicate with one another during the school vacations. As a result, a Skype group was created, so that the team could hold Skype calls to continue working on the challenge. This is also when Google Drive became handy as the group was able to upload the files that anyone created and they could be accessed anytime and anywhere. Google Drive was also useful because multiple people could be on the same document at the same time.

Another challenge that the team had to face was learning the CAD modeling program. Rather than designing the 3D CAD model in Creo, the team decided to design it in AutoCAD 2014 since it offers more functions and it is more convenient. Also, AutoCAD 2014 was available for both Mac and Windows, whereas PTC Creo was only available for Windows. Since all of the team's members have Macs, the team members were able to share design ideas among each other instead of using the only Windows computer in the library, while the team's meetings were being held in the science center. Despite these challenges, the team worked together to overcome and persevere.

## 1.5 Impact on STEM

RWDC has taught the team that STEM requires a lot of thinking, brainstorming, and communication. Engineering requires collaboration, experience, and reiteration in order to create a final product. At the beginning, the team jumped right into the research and started brainstorming designs, but the team did not have a clear plan to complete the challenge. As the group advanced in the challenge, answering one question lead to another, so the team started making more decisions and eventually finalized a design.

Each of the team's members has now found new passions in STEM that they had not had before, thanks to RWDC. RWDC has shown Kunal the complexity of the engineering process, and the numerous factors and steps needed to make even the simplest of decisions. Alex has experienced the intricacy of an engineering project specifically in the brainstorming, planning, and research processes. Vish learned how to prioritize equipment on drones, and this has given him an appreciation for each piece of C3 equipment. Vish and Alex have also gained a new understanding of the way the design process works, and how science, technology, engineering, and mathematics work together to make it thrive. Through the RWDC design process, Ruide realized the dependency of different design factors on each other and that these factors must be prioritized in order to reach a decision. He also learned that nothing in engineering is about solo work. Steve learned that there are multiple aspects to a business case that he did not know about before. Sebastian learned that it is important to establish strong connections with each member of the group in order to create a very strong final journal.

In terms of career paths, all team members are interested in different things: software engineer (Kunal), mechanical engineer (Alex), electrical engineer (Vish), aeronautical engineer (Reader), physicist (Steve), and investment banker (Sebastian).

While looking for team members for the club, Kunal, Vish, Ruide, and Alex participated in Phillips Academy's biannual club rally. Using colorful posters depicting pictures of UAVs and CAD models on the RWDC website and online, along with their own shouts and yells, they were able to entice many students to sign up for the club. The method of member acquisition was quite successful and it generated excitement for STEM and design in the student body.

# Chapter 2

# Document the System Design

## 2.1 Mission Design

### General Information

All of the missions utilize the same drone, BluSkye, designed by the team to maximize payload capacity, endurance, and speed. As a high end drone, BluSkye retails for over $9,000. After an analysis of the annual income of corn farmers, the team recognized that only approximately the top 20% could afford this precision agriculture drone to help maximize productivity and yield. The majority of these farmers utilize a system of center pivot irrigation to minimize labor and maximize yield. Center pivot irrigation is a circular farming system used for both irrigation and chemigation. The equipment rotates around a central pivot on fields with a diameter of 0.5 miles. This method of farming is extremely popular among farmers. Thus, each mission is marketed specifically towards center pivot irrigation to custom fit the consumer base.

The following table lays out the basics of the logistics, survey, and dash missions:

| | **Logistics** | **Survey** | **Dash** |
|---|---|---|---|
| **Payload** | There: GoPro & gimbal, CPI motor, and fuel<br>Back: GoPro & gimbal, CPI motor, and fuel | Sequoia sensor, Sequoia Gimbal, GoPro, GoPro gimbal, and fuel | Sequoia sensor, Sequoia Gimbal, GoPro, GoPro gimbal, and fuel |
| **Purpose of Mission** | To transport replacement CPI parts | To scan for crop health | To scan for nitrogen streaking and determine the extent of damage |
| **General Flight Plan** | 1 mile across field(s) and back | Survey 25 square miles | 1 miles and back |

Table 1: Basics of the Logistics, Survey, and Dash Missions

### The UAV

In order to maximize efficiency and quality, the team created a drone, BluSkye, that was based off of the Aerohawk and increased effectiveness of the crucial features of a precision agriculture drone, specifically payload capacity, endurance, and speed. The features are shown below:

| | |
|---|---|
| **Payload** | 33.86 lb ($<$ 21.44 lbs due to FAA regulations) |
| **Weight** | 33.46 lbs with engine |
| **Max Takeoff Weight** | 54.99 lbs |
| **Top Speed** | 87 knots |
| **Endurance** | $>$ 7 hours |

Table 2: BluSkye Payload, Speed, and Endurance

### Logistics Mission

Center pivot irrigation is a prevalent aspect among the farmers catered to, so each missions works to fix issues facing them, especially in that area. When farms are irrigated or sprayed with pesticide using center pivot irrigation, there is always at least one employee out monitoring the system. However, if one of the center pivot irrigation's motors fails, the entire system has to stop until the motor is replaced. The logistics mission fixes that problem by flying a motor, which weighs 20.25 lbs, to another farmer working to discover the issue with the center pivot irrigation system in just over a minute. The overall payload ultimately includes 20.25 lbs of a new center pivot irrigation motor, along with 0.46 lbs of fuel, a 0.27 lb GoPro HERO5 Session, and a 0.34 lb GoPro gimbal. The UAV returns with the broken motor, the GoPro and gimbal, and the remaining fuel. The outgoing and returning trip's payload is roughly 21 lbs.

### Survey Mission

Determining the crop health of a field is a crucial use for an agricultural drone. This allows farmers to properly treat their plants specifically based on their health. The team's survey mission scans for crop health over 25 square miles at 394 feet (120 meters) and 40 knots. The mission payload consists of the Sequoia sensor (0.24 lbs), a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), a GoPro HERO5 Session (0.27 lbs), and a GoPro gimbal (0.34 lbs). The Sequoia sensor is an advanced agricultural sensor designed and built by Parrot. At 0.24 lbs, it is unbelievably light, yet also offers a sunlight sensor, which logs current lighting conditions to refine and calibrate other measurements from the system. When the UAV is flown over the field, the Sequoia sensor is deployed to scan for crop health by detecting multiple telltale signs of unhealthy crops, including symptoms of nutrient deficiencies and biotic stress. A snakelike flight plan was designed, so the UAV will fly across 1.0 mi x 1.0 mi fields[1], making turns with 264 foot radii[2] while scanning the crops. This turn radius maximizes the area covered, because it ensures that area scanned by the Sequoia sensor will not be re-scanned when the plane returns. In order to ensure proper endlap and sidelap for the Sequoia sensor, the survey mission is conducted at 394 feet (120 meters) and 40 knots, which ensures the required endlap of greater than 70%. The mission also features 25% sidelap per the Sequoia user manual. Flying with 20.18 lbs of fuel, over 25 fields can be scanned (for a total of 25 square miles). The plane burns approximately 0.06 lbs of fuel per mile covered, so the plane will have about 1.5 lbs of fuel remaining, which can be used for takeoff and landing and in case of emergencies.

**Dash Mission**

Nitrogen streaking is a prevalent problem on center pivot irrigation farms and causes about a billion bushels of lost yield in the Midwest. Scanning for it and finding it in the early stages can increase yield and prevent the loss of thousands of dollars per year. So, the team's dash mission is about detecting nitrogen streaking. In the dash mission, the payload consists of fuel (2.75 lbs), the Sequoia Sensor (0.24 lbs), and a 2 Axis Parrot Sequoia Stabilized Gimbal (0.40 lbs) to balance and attach the sensor, a GoPro HERO5 Session (0.27 lbs), and a GoPro gimbal (0.34 lbs) for a total payload weight of exactly 4 lbs. In this instance, the Sequoia sensor and camera are employed to determine if crop streaking is present in a field and then determine the extent of the damage of it. The UAV will fly out for 1 mile at 87 knots at 230 feet. When flown 1 mile, data from the Sequoia sensor can be cross referenced with images from the GoPro to determine the extent of the crop streaking. Because of the high speed at which this mission is conducted, it only takes minutes to complete. The team recognizes that due to the speed, the Sequoia will execute the mission with improper endlap. This will result in an incomplete set of data; however, it will still be able to identify the crucial aspects that the mission targets: if it is present and the severity. These scans help farmers to determine whether to abandon a field, treat it, conduct extensive scans with a survey-type mission, or continue the current practices in order to maximize yield and productivity.

**Additional Agricultural Missions**

The team designed 13 additional agricultural missions, all of which fly at 394 feet and 40 knots to minimize time and maximize the quality of the scans. 40 knots at 394 feet also

[1] See section 3.2 for explanation

[2] Section 2.7 explains the derivation of this

allows for the 70% sidelap required by the Sequoia sensor. The Sequoia sensor, Sequoia gimbal, GoPro HERO5 Session, GoPro gimbal, and fuel make up the total payload, for a total of 21.4 lbs. The farmer uses the survey mission flight plan to increase scanning power. Each mission utilizes just over 20 lbs of fuel so the farmer can scan for over 7 hours. Up to 25 square miles can be thoroughly covered, depending on a farmer's preference. Details of how each mission assists the farmer are as follows:

| Mission | Payload | Purpose of Mission | General Flight Plan |
|---|---|---|---|
| Moisture Detection | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To determine the moisture content of the crops | Snake-like pattern |
| Infestation Detection | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To find any crops that have been infested | Snake-like pattern |
| Weeds Detection | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To detect any weeds growing within the crops | Snake-like pattern |
| Creating VRA Maps | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To determine the strength of nutrient uptake in a single field | Snake-like pattern |
| Time-Series Animation | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To take multispectral images in a single field | Snake-like pattern |
| Creating Reflectance Maps | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To create a map that would help the farmer with increasing yields | Snake-like pattern |
| Biomass Detection | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To find biomass in crop residues in order to produce energy | Snake-like pattern |
| Harvest Yield Estimation | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | Count plants and size/number of product to predict income for that season | Snake-like pattern |
| Scouting Fertile Land | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To find fertile land | Snake-like pattern |
| Livestock Monitoring | Sequoia sensor, Parrot gimbal, GoPro & gimbal, and fuel | To track the livestock in a field | Snake-like pattern |

Table 3: Basics of the Additional Missions

| Mission | Explanation of Assistance |
|---|---|
| Moisture Detection | Allows farmer to adjust irrigation practices to cater to plants needs, thus increasing yield |
| Infestation Detection | Identifies pest "hotspots" so they can be dealt with, thus increasing yield |
| Harvest Yield Estimation | Allows farmers to estimate labor and time need when it's time to harvest crops |
| Creating VRA Maps | Allows farmers to recognize unhealthy plants so they can treat individually to increase yield |
| Time-Series Animation | Shows farmers ongoing trends so they can adjust their farming practices to increase yield |
| Creating Reflectance Maps | Allows farmers to understand current trends to adjust current farming practices |
| Biomass detection | Reduces disposal costs, pollution, increases energy independence, and "eco-friendliness" |
| Scouting Fertile Land | Allows farmers to expand effectively onto fertile land to maximize yield |
| Livestock Monitoring | Allows farmers to recognize and track current livestock to keep track of them |
| Weed Detection | The detection of weeds prior to harvest prevents damaging invasions from increasing in size |

Table 4: Explanation of Assistance for Additional Missions

### The Influence of Safety on Mission Design

The team also worked to maximize the safeness of safety throughout the aircraft. The following systems were implemented:[3]

- **Latas Ground** – allows a drone operator to cross reference obstacles, buildings, etc. with the planned flight path.
- **Latas Air** – provides live FAA feeds so that drone operators can avoid airports, illegal flying zones, aircraft, and areas with forest fires or another temporary restrictions on drone flight.
- **Autopilot** – conducts the entire mission based on an entered flight plan in order to prevent human error. The system will also submit the flight plan to Latas Air so that other drone operators in the area are aware of flight paths to prevent incidents.

[3] See section 3.5 for an in-depth look at this

- **Emergency return switch** – allows a pilot to automatically recall the drone at any time with the click of a button.
- **Automatic return** – If either GPS signal or radio signal is lost, the drone will fly on a direct course back to the point of origin based on how many miles traveled and the angles executed.
- **Glonass Positioning System** – This positioning system provides extensive cross checking of the current location of the UAV in order to meet the mission of precision agriculture
- **Obstacle avoidance** – The team recognized that the UAV is flying too fast for typical obstacle avoidance systems. Thus, a range finder was instituted to alert the drone if there is something in the path. The UAV will execute a preprogrammed flyover in the event of this.
- **5 point takeoff requirement check** – A safety check that the licensed operator must execute prior to takeoff built into the software.
- **Landing and takeoff altitude rangefinder** – The team implemented a rangefinder facing downward to determine the current altitude to increase the precision of both the takeoff and landing to prevent collision an avoid obstacles in flight.

These safety implementations provide multiple failsafe measures against anything that goes wrong, effectively making the entire UAS one of the safest systems on the market.

## 2.2 Conceptual, Preliminary, and Detailed Design

To design this drone, a clear plan for research and analysis was needed. Also, being a team effort, communication was critical to understand the collective mindset towards the design process. So, the team first created a strategy for how to attack the challenge, then established means of communication through Skype, Google Docs, and group chats. This system not only allowed decisions to be made efficiently, but also allowed research to be shared quickly, which in turn aided the design process.

In the first two weeks, the team started considering which airframe to use, which crop to choose, and what payloads are be useful for a farmer. The first step was to analyze the challenge. The team read over the rules and the detailed background and then summarized these documents. At every weekly meeting, the team collectively went over these documents again, so that everyone was on the same page about each of the missions. Then, each person was assigned a task, such as analyzing the objective function to see what factor was most important for each mission, comparing airframes to find the most well-rounded one, or finding a useful payload for each mission.

### 2.2.1 Engineering Design Process

In order to solve a problem or create a novel product, engineers and designers use the engineering design process. Though the process varies depending on the specific application the team stuck to the basic engineering process as follows:

1. Define the Problem
2. Conduct Background Research
3. Brainstorm Solutions
4. Select the Best Solution
5. Develop the Idea
6. Construct a Model (CAD Model / Business Plan)
7. Assess Viability
8. Refine the Design (Redesign)

To define the problem, the team read over the rules and detailed background, and identified the minimum requirements and any important regulations. Also, the logistics, survey, and dash missions were summarized so that everyone had a comprehensive understanding as to what each mission's goal was. Then background research was done to identify crops in the area and find payloads that are the most beneficial for a farmer. The team took this research and began brainstorming solutions for each mission. Once a sizable list of potential resolutions was created, each one was scrutinized and evaluated. In this process of narrowing down solutions, the team first tackled the issue of payload. With each main mission having a different payload, individualized solutions for each mission were selected, rather than one payload that satisfies all missions. This decision gives farmers variability and allows them to be resourceful by using one drone for many different applications. The final payload decisions were:[4]

- Logistics Mission: Center Pivot Irrigation Motors, GoPro + Gimbal, and Fuel
- Survey Mission: Sequoia Sensor & Gimbal, GoPro + Gimbal, and Fuel

[4] Sections 3.1, 3.2, and 3.3 give details about the reasons for each payload

- Dash Mission: Sequoia Sensor & Gimbal, GoPro + Gimbal, and Fuel

While choosing payloads, the team also gauged their value to the farmer in order to make sure that they were efficient as well as useful.

Next in the process of narrowing down solutions, the team addressed the UAV's airframe. Because of the need to satisfy the logistics, survey, and dash missions as well as have the flexibility for additional applications, the airframe had to maximize on three things: speed, flight time, and payload capacity. These three considerations were extremely important for the UAV, so much time was spent mathematically analyzing the objective function to find their maxima and minima. Once the team understood the baseline speeds, flight times, and payloads that needed to be reached, an airframe was found that matched that criterion.

After developing the idea a little more, the Andover Blueprints continued on to create a CAD model, so the team could physically see the concepts that were being visualized. Even more importantly, the business model was then discussed and created around the team's vision (Chapter 4 elaborates). This was the phase of the engineering design process where the team finally had a comprehensive view of the product and business.

With this in-depth perspective, the team took a step back from the details to assess the viability of solutions as a whole. Each mission was once again reviewed and then the whole team scrutinized the solutions.

Throughout the whole engineering design process, almost all decisions, solutions, calculations, etc. were reconsidered and revised. In fact, after the results of the State Competition were released, the Andover Blueprints took the judges' comments and assimilated them, and re-evaluate and redesign. This iterative process is why engineering is such a great method to design and create something. If a decision doesn't satisfy the team: reconsider all the options! If a solution seems feeble and hollow: redesign! If the business is not viable in the market: rethink and redesign! Because this UAS went through much iteration as such, the team is confident in its integrity and ability.

### 2.2.2 Conceptual Design

After identifying all the restrictions the aircraft had, both legal and those imposed by RWDC, the team still had enumerable possibilities for the design. After research, lighter-than-air UAVs were not considered due to a slow speed and lack of precision.

Rotorcraft, hybrid, and fixed wing aircraft were considered as designs for the airframe.[5] The pros and cons are shown below:

[5] The team determined that lighter-than-air aircraft would not be able to compete in the precision agriculture industry due to a low payload capacity and slow speed, along with their low maneuverability and high likelihood of getting blown off course.

| **Considerations** | **Rotorcraft** | **Hybrid** | **Fixed Wing** |
|---|---|---|---|
| Speed | Rarely higher than 50 knots | Scattered | Up to 87 knots |
| Endurance | Very low | Moderate | Extensive |
| System cost | Moderate ($5000 - $15,000) | Expensive (upwards of $10,000) | Moderate (Most are less than $10,000) |
| Fuel Efficiency | Very poor | Poor to moderate | Adequate/Very good |
| Payload Capacity | 15 lb maximum | Moderate– less that 20 lbs | Typically high (20 lbs or higher) |
| Maneuverability | Very good | Good | Poor |
| Availability | Widely manufactured and available | Rare | Moderate availability |

Table 5: Pros and Cons of Rotorcraft, Hybrid, and Fixed Wing Aircraft

Despite lacking maneuverability, a fixed wing aircraft maximizes flight time, payload capacity, and speed. Thus, the team chose to utilize a fixed wing airframe. From there, the Andover Blueprints then had chosen between a pusher and tractor design. The pros and cons are listed below:

| | Pros | Cons |
|---|---|---|
| **Tractor** | Propeller receives direct, undisturbed airflow<br>Doesn't require long takeoff and landing space<br>More maneuverability | Slower |
| **Pusher** | Extensive endurance<br>High payload capacity and speed | Requires runway<br>Only moderately maneuverable |

Table 6: Pros and Cons Tractor and Pusher Designs

A fixed wing pusher design was ultimately chosen as the ideal airframe because it is more energy efficient than an airframe with rotors. Fixed wing pushers are also significantly stronger and more stable than other designs, allowing them to carry enough payloads to execute the operation. The team chose to use a wheeled landing because it is safer, cheaper, and more energy efficient than the other landings (parachute and belly). For example, a parachute landing often fails to prevent expensive airframes from hitting the ground hard, and belly landings can damage a UAV. Additionally, belly and parachute landings can require large and expensive towed launchers.

After the landing mechanism was decided, the propulsion needed to be determined. The team chose a gas engine because of its efficiency and cost. Batteries are heavy, expensive, and can take hours to charge, while gas is cheap, offers much longer range and flight time, and can be refueled in an instant. Thus, a gas engine was an obvious choice.

After determining the above, the conceptual designs were picked out. The conceptual designs were influenced by: payload capacity (the aircraft has to be able to carry the chosen sensor and payload), endurance time (the aircraft must finish its missions), cruise speed (this affects the turning radius of the aircraft, which in turn affects the flight plan), cost (cost-efficient for wider distribution to increase business profitability), weight (affects the bank angle of the aircraft and max payload), landing method (usable in a farm environment), takeoff method (affects time of operation), and regulation (meets all FAA drone regulations).

Seven designs were ultimately considered. Specifications and images are shown below:

*Consideration 1*: Theia Operational UAS[6]

Figure 3: Theia Operational UAS Image

| | |
|---|---|
| **Payload** | 55.12 lbs |
| **Weight** | 110.24 lbs |
| **Cost** | N/A |
| **Speed** | 81.00 knots max |
| **Endurance** | up to 24 hours |
| **Engine** | 4-stroke 110cc |
| **Takeoff/Landing** | Wheel/Wheel |

Table 7: Theia Specifications

*Consideration 2*: UAV Strix[7]

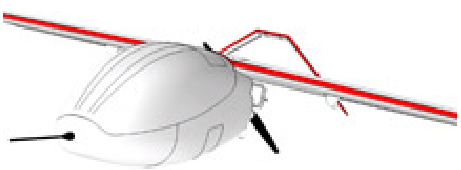


Figure 4: Strix UAV Image

| | |
|---|---|
| **Payload** | 39.7 lbs |
| **Weight** | 66.1 lbs |
| **Cost** | N/A |
| **Speed** | 86.39 knots |
| **Endurance** | 15+ hours |
| **Engine** | 10 HP, 100 CC |
| **Takeoff/Landing** | Launched by hand |

Table 8: Strix UAV Specifications

*Consideration 3*: HAVOC[8]

Figure 5: HAVOC UAV Image

| | |
|---|---|
| **Payload** | 45 lbs |
| **Weight** | 84 lbs |
| **Cost** | N/A |
| **Speed** | 102.54 knots |
| **Endurance** | 18 hours |
| **Engine** | N/A |
| **Takeoff/Landing** | Manual or auto rolling |

Table 9: HAVOC UAV Specifications

[6] http://www.threod.com/products/uas-theia/theia-description
[7] http://www.aerodreams-uav.com/es-uav-strix.html
[8] http://www.brocktekus.com/havoc

*Consideration 4*: SPEAR[9]

Figure 6: SPEAR UAV Image

| | |
|---|---|
| **Payload** | 10 lbs |
| **Weight** | 21 lbs |
| **Cost** | N/A |
| **Speed** | 64.00 knots |
| **Endurance** | 2.8 hrs gas, 1 hr electric |
| **Engine** | Gas preferred over electric |
| **Takeoff/Landing** | Manual/Belly skid |

Table 10: SPEAR UAV Specifications

*Consideration 5*: BOREAL[10]

Figure 7: BOREAL UAV Image

| | |
|---|---|
| **Payload** | 11 lbs |
| **Weight** | 55 lb MTOW |
| **Cost** | N/A |
| **Speed** | 97.33 knots |
| **Endurance** | 10 hours |
| **Engine** | 100W, 12V electric |
| **Takeoff/Landing** | Manual/Automatic |

Table 11: BOREAL UAV Specifications

*Consideration 6*: InSitu Group Scaneagle A-15[11]

Figure 8: Scaneagle UAV Image

| | |
|---|---|
| **Payload** | 13.2 lbs |
| **Weight** | 26.5 lbs |
| **Cost** | Less than $100,000 |
| **Speed** | 69.52 knots |
| **Endurance** | 28 hours |
| **Engine** | 2.5hp gas engine |
| **Takeoff/Landing** | Launcher/belly landing |

Table 12: Scaneagle UAV Specifications

*Consideration 7*: Aerohawk[12]

[9] http://www.brocktekus.com/spear
[10] http://www.xamen.fr/index.php/fr/produits/boreal.html
[11] http://www.barnardmicrosystems.com/uav_list/scaneagle.html
[12] http://www.asiatechdrones.com/_p/prd1/4554854371/product/aerohawk-*-bare-airframe

Figure 9: Aerohawk UAV Image

| | |
|---|---|
| **Payload** | 33.86 lbs |
| **Weight** | 33.07 lbs with engine |
| **Cost** | $5,200 |
| **Speed** | 87 knots |
| **Endurance** | 4.5 hours |
| **Engine** | 55CC gas engine |
| **Takeoff/Landing** | Wheel/Wheel |

Table 13: Aerohawk UAV Specifications

Ultimately, the team chose the Aerohawk's design and made several modifications to it. This was to cut costs and increase efficiency because it was discovered that a similar airframe can be manufactured for a fraction of the cost of one built by another company. This also allowed the team to modify the airfoils and maximize efficiency. Additionally, an almost identical engine was bought from another company rather than from the airframe maker at a much cheaper price.

### 2.2.3 Preliminary Design

The team then created a ranking system that allowed us to quantitatively evaluate each airframe. The ranking system evaluated each airframe for the following categories: maximum payload, empty weight, cost, and endurance. Here is the ranking system:

| Name of UAV | Max Payload (lb) | Empty Weight (lb) | Cost ($) | Max Speed (knots) | Endurance (hr) |
|---|---|---|---|---|---|
| Theia Operational UAS | 55 lbs | 110 lbs | n/a | 81 knots | 24 hrs |
| UAV Strix | 39 lbs | 66 lbs | n/a | 86 knots | 15 hrs |
| HAVOC | 45 lbs | 84 lbs | n/a | 103 knots | 18 hrs |
| SPEAR | 10 lbs | 21 lbs | n/a | 50 knots | Electric: 1 hr<br>Gas: 2.8 hrs |
| BOREAL | 11 lbs | 44 lbs | n/a | 100 knots | 10 hrs |
| InSitu Group Scaneagle A-15 | 13.2 lbs | 26.5 lbs | $< \$100,000$ | 70 knots | 15 hrs |
| Aerohawk | 30.86 lbs | 33.07 lbs | $5,200 | 87 knots | 10 hrs |

Table 14: Comparison of Different UAV Options

While choosing the final design, the team was primarily influenced by each airframe's maximum payload and empty weight. The team first eliminated SPEAR because its maximum speed was way too low for it to be used in the dash mission and because its endurance was too low for the survey mission. Then, the team eliminated Theia Operational UAS, UAV Strix, HAVOC, and BOREAL because their empty weights were so high that having a heavy payload weight for the logistics mission would not be realistic or not possible. This left the team between InSitu Group Scaneagle A-15 and the Aerohawk. The team liked the Aerohawk due to its higher maximum payload weight and because the maximum speed of

InSitu Group Scaneagle A-15 was not high enough for the dash mission (exactly 87 knots). The Aerohawk also carries a 55CC gas engine, which allows it to stay aloft for an increased period of time. It met all federal drone regulations and was at a reasonable price.

The team also researched the Human Factors Analysis and Classification System (HFACS). This identifies the cause of a UAV accident and "provides a tool to assist in the investigation process and target training and prevention efforts." The team worked to identify the possible human factors that could cause a mishap. Recognizing that around 80% of malfunctions with normal aircraft are the result of human error, the team implemented an autopilot system to decrease the likelihood of any incident.

Following the state challenge, the team began to look into alternative designs to reduce costs and maximize payload capacity and endurance. An alternative drone was built to cut costs because the materials could be acquired for $250.00. This drone was similar in design to the Aerohawk, but the team significantly changed the fuselage to increase the payload and then modified the airfoils and streamlined the design to increase efficiency. This resulted in a drone called BluSkye, and it is fast, durable, agile, and efficient. The engine cost was reduced by purchasing from an alternate seller, which furthermore improved the final product. Additionally, the team implemented modern safety measures and built them into the airframe with more ease. By designing and building the controller, the team was easily able to integrate LATAS Air and LATAS Ground into the UAS. The team built the best UAV by borrowing crucial features from current drones in the market and then built on that by implementing key capabilities required for precision agriculture drones.

### 2.2.4 Detailed Design

In order to design BluSkye, the Andover Blueprints designed a commercial UAV platform to successfully execute the selected missions and any additional applications for a customer while also prioritizing safety. The team looked for fixed wing pusher UAVs with gas engines for increased speed and endurance to satisfy the Andover Blueprints' high standards while maintaining an extremely affordable price-point. The team focused on the logistics, survey, and dash missions, so the top three priorities while choosing the drone were high speed, a long flight time, and the payload it can carry (volume as well as weight). In the state challenge, the team chose the Aerohawk by Asia Tech Drones out of the varying options given in section 2.2.2 because of its well rounded and powerful design. The Aerohawk was a strong compromise for the time being but there were countless improvements to make, including reducing the cost, lowering the weight, increasing the payload weight, and expanding the volume of the cargo bay. The team decided to make many modifications to create the ideal drone platform for the customers and their applications and thus BluSkye was born.

BluSkye is perfect for its purpose because it is fast, durable, agile, able to complete long missions, and can carry over 30 pounds of payload. The system can be deployed for data collection missions (the primary focus of the Andover Blueprints' business) and conduct missions. The large hull caters to both of these applications to carry large, heavy materials or contain large amounts of fuel, as well as many sensors and processors.

After creating BluSkye, the team calculated the maximum bank angle the aircraft could safely sustain in a turn. Calculating the bank angle (in section 2.7) affected the mount the team later chose and allowed the team to calculate the minimum turning radius of the aircraft. This was essential in determining the most efficient flight plan for a range of applications in agriculture and beyond.

Next, the team deliberated over an appropriate primary sensor (section 2.3.1). The group chose the Sequoia multispectral sensor from Parrot and MicaSense. This multispectral sensor was appropriate because of its excellent quality is and relatively low cost. It is over $2,000 dollars cheaper than the X5000 sensor, the team's original pick from the detailed background, and includes an irradiance sensor as well as more flexibility in terms of bands of light and lenses. The sensor's specifications are:

| **Sensor** | X5000 Multispectral Sensor | Sequoia Multispectral Sensor |
|---|---|---|
| **Cost** | $5,500 | $3,400 |
| **Multispectral Sensor Size** | 2.5 in (width) x 2.5 in (length) x 2.0 in (height) | 1.6 in (width) x 2.3 in (length) x 1.2 in (height) |
| **Irradiance Sensor Size** | n/a (no irradiance sensor) | 1.6 in (width) x 1.9 in (length) x 0.7 in (height) |
| **Weight** | 1.4 lbs | 0.24 lb |
| **Field of View** | 40° (horizontal) x 20° (vertical) | 70.6° (horizontal) x 52.6° (vertical) |
| **Resolution** | 3.15 MPX | 16 MPX |
| **Bands of Light** | Green, Red, NiR | Green, Red, Red Edge, NiR, RGB |
| **Maximum Range** | 500 feet | 500 feet |

Table 15: X5000 vs Sequoia Sensor Specifications

The group also needed a mount to stabilize the sensor and keep it pointing down when the UAV turns. The team decided to use a 2 Axis Parrot Sequoia Stabilized Gimbal ($95). This cost-effective option was chosen over a GoPro mount that could be modified to fit the Sequoia sensor. This gimbal is specifically designed for the Sequoia sensor and ensures excellent stabilization, as well as good pitch and roll limits for the product. Here are the mount's specifications:

| | |
|---|---|
| Cost | \$95 |
| Stabilization | Excellent |
| Size | 3.7 inches (width) x 3.9 inches (length) x 4.0 inches (height) |
| Weight | 0.397 lbs |
| Roll Limit | 45° |
| Pitch Limit | 45° |

Table 16: Parrot Sequoia Mount Specifications

Additionally, the team calculated the Sequoia's field of view. These drawings showed that the sensor's horizontal field of view was sufficient to measure 325.698 feet laterally, which is roughly 108 rows of corn (each row being 3 feet), as well as 227.346 feet vertically which correlates to a high maximum speed. To make sure that the detected data is accurate, the UAS takes measurements with 25% sidelap and 70% endlap in order to focus on the clearest images, which are directly below the sensor.

At an altitude of 230 feet (the ideal altitude for the Sequoia sensor), the camera can view 325.698 feet in the direction perpendicular to the way the UAV is flying:

$$tan(35.3) = \frac{\frac{1}{2}x}{230ft}$$

The Sequoia can collect data for 227.346 feet in the direction the UAV is flying:

$$tan(26.3) = \frac{\frac{1}{2}x}{230ft}$$

### 2.2.5 Lessons Learned

In each design phase, the team learned how to organize its decisions and prioritize factors of the design. Because so many calculations depend on one another (i.e. cruise speed affects turning radius, which affects the flight plan), the team needed to communicate really efficiently. Since the team is based in a boarding school, it was difficult communicating over the break. Eventually, the team set up several Skype meetings and productively worked together. This design process taught us that collaboration is the key to success.

### *Conceptual Phase*

During the conceptual phase, the team learned that conducting research does not mean clicking and reading links on the first or second pages of a web search and then coming to a conclusion; but rather, conducting research means going to the fourth, fifth, sixth (etc.) pages of web searches and perusing content to extract important information to come up with a logical conclusion. It also means using resources like books, articles, newspapers, scholarly articles, research papers, etc. to gather further information, rather than just relying on web searches. The team found several articles about drones from places such as Business Insider, The Huffington Post, The New York Times, etc. to help us with decision-making. All of this research helped the team consider many different conceptual designs and exhaust all of the options. (See Chapter 6 for a full list of references.)

#### *Preliminary Phase*

During the preliminary phase, the team learned to manage time efficiently. At the beginning of the challenge, the team was taking lots of time to finalize things. To prioritize, the team created a "tasks to do" schedule to figure out what needed to be accomplished each meeting. At the beginning of every meeting, the team projected the schedule on the projector (so that everyone was on the same page) and eliminated each task as it was completed. This helped the team manage its time to maximize the value of each meeting, while not wasting any precious time.

#### *Detailed Phase*

During the detailed phase, the team learned that even though certain decisions were agreed upon by all team members, things could still change, depending on the situation. For example, early on, the team agreed on the basics of the three minimum-required missions (logistics, dash, and survey), like the payload and the purpose of the mission. However, as the team progressed and better understood the challenge, the team identified many flaws with the payloads that were originally agreed upon, and so, the payloads were changed, which in turn, changed the purposes of the missions.

### 2.2.6 Project Plan Updates and Modifications

One of the original things that the team did was assign roles to each member: for example, one person to work on the CAD and design analysis and others to handle the flight plan. At first, the team's research was very disorganized and hard for other team members to understand. The team reorganized the research on Google Drive by sorting it into tables and outlines. In this way, each team member could reference the team's research more quickly. Before the team chose to base its final design off of the Aerohawk, the team ran through several designs: the team's first design was the Theia, but its payload was 55 lbs, which is the exact limit specified by the FAA. The team wanted to significantly reduce the payload weight, so the team changed its design to mimic the Spear. However, the payload weight of the Spear was 10 lbs, and after some analysis on the objective function, the team realized that the ideal payload weight would be around 20 lbs. Thus, the team changed its design again to mimic the Aerohawk. During each design phase, the team went through four iterations to develop the best possible UAS.

## 2.3 Selection of System Components

Selection of the aircraft's components was a crucial step in the design process. Deciding what the UAV should do for the customer and choosing the payloads gave the team a distinct idea of which airframe to use. The airframe type was very dependent on the payload; it needed to be able to carry out each mission and had to be extremely adaptable to fit all of the needs the team laid out. When choosing the system components, the team created tables on Google Drive to compare each possible candidate, while keeping price and functionality in mind. The team split into groups to focus on each component and discuss the pros and cons of each decision. Later, the group made sure to review, discuss, and finalize everything together to look at other ideas and really make sure that the product makes sense and can serve farmers in real world commercial applications.

### 2.3.1 Payload Selection

After the team conceptualized the logistics, dash, and survey missions, the group began brainstorming effective strategies.

#### *Logistics Mission*

For the logistics portion of the challenge (section 3.1), the team wanted to transport materials around a farm to aid farmers as it is difficult to drive a truck around everywhere and such tasks must be completed rapidly and for a low cost. After researching and asking local farmers what farmers need to carry around a farm and how the team's UAV could play into this, the team had a few payload options: pest traps, seeds, fertilizer/pesticide (diluted or concentrated), motors and irrigation rig components, or tools.

To narrow down the options, the team decided that transporting water, fertilizer, and seeds is pointless since our target group of customers is the top 20% most successful farmers. These farms all have automatic irrigation, fertilization, pesticide spraying, and seed planting systems. None of these would be done manually in a small area of the field with a UAV. Industrial farms also widely use pesticide so the team ruled out the pest traps mission. The Andover Blueprints finally decided to carry materials to maintain or fix a broken irrigation rig. The team decided that the UAV will carry a 20.25 pound motor to the location of the broken central pivot irrigation motor and return the broken motor. The group decided to carry it within the hull of the aircraft.

### ***Survey Mission***

For the survey mission, the group decided to monitor overall crop health. This was deemed a useful primary mission because a farmer can execute it fairly easily. If the crop efficiency and health is not optimal, customers can perform other applications of the UAV such as monitoring moisture content, weed detection, measuring nutrient levels in the soil, and more. To perform this task, the team narrowed the payload possibilities down to the following categories of sensors and approaches to the problem at hand: monitor crop color or growth rate (CCD/CMOS camera) or monitor the amount of chlorophyll in leaves (multispectral/hyperspectral sensor).

To decide which approach to use to detect overall crop health, the team used a rigorous decision making process (which was also employed to choose the sensor for the dash mission) that involved through many stages of eliminating unfit options, while keeping in mind the other functions of the UAV. At first, the team considered utilizing an indicator crop as a way to determine the overall health of the useful crop, as it would be the simplest solution to the problem. Soon after, the members realized that this would be a highly unreliable and inaccurate option because the crops would be different and there is no precise correlation between the plants; so it was decided that mounting a sensor or multiple sensors would be a better plan.

The group began by compiling all of the different sensors that had been researched by the team members. By separating the possible sensors into two categories, direct (radar, infrared, thermal) and indirect (cameras), the team members were able to start evaluating and comparing the sensors given in the detailed background.

With CCD/CMOS sensors:

| | X250 Sensor | X500 Sensor | X1000 Sensor | X2000 Sensor | X3000 Sensor |
|---|---|---|---|---|---|
| **Cost** | $30 | $50 | $5,000 | $15,000 | $17,000 |
| **Size (*l* x *w* x *h* in mm)** | 24 x 18 x 10 | 22.5 x 11.5 x 8 | 63.5 x 63.5 x 50.8 | 102 x 102 x 25.4 | 127 x 127 x 57.2 |
| **Field of View (horizontal x vertical [FOV])** | 62°x 30° | 90°x 80° | 40°x 20° | 55°x 5.5° | 25°x 19° |
| **Resolution (horizontal x vertical [px])** | 656 x 492 | 656 x 492 | 640 x 480 | 640 x 480 | 640 x 480 |
| **Weight** | 0.18 oz | 0.18 oz | 0.5 lb | 2.1 lb | 3.5 lb |
| **Stabilization** | poor | poor | good | excellent | excellent |
| **Zoom** | n/a | n/a | n/a | 10x | 4x continuous zoom IR<br>3x continuous zoom visual |
| **FOV When Zoomed In** | n/a | n/a | n/a | 41.25 x 4.125 | n/a |
| **Roll Limit** | n/a | n/a | 30° | 80° | 85° |
| **Pitch Limit** | n/a | n/a | 30° | 80° | 85° |

Table 17: Comparison of Sensors With CCD/CMOS

Without CCD/CMOS sensors:

| | X4000 Sensor | X5000 Sensor | X6000 Sensor |
|---|---|---|---|
| **Cost** | $20,000 | $5,500 | $15,000 |
| **Size (*l* x *w* x *h* in mm)** | 102 x 102 x 25.4 | 63.5 x 63.5 x 50.8 | 12.5 x 12.5 x 4.75 |
| **Field of View (FOV)** | 30°x 25° | 40°x 20° | 40°x 20° |
| **Resolution (px)** | 640 x 480 | 2048 x 1536 | 1280 x 1024 |
| **Weight** | 3 lb | 1.4 lb | 7 lb |
| **Stabilization** | excellent | excellent | excellent |
| **Zoom** | 8x continuous zoom | n/a | n/a |
| **FOV When Zoomed In** | n/a | n/a | n/a |
| **Roll Limit** | 80° | 30° | 70° |
| **Pitch Limit** | 80° | 30° | 70° |

Table 18: Comparison of Sensors Without CCD/CMOS

The Andover Blueprints soon realized that an indirect sensor (CCD/CMOS camera) is not useful because the product has to accurately measure the health of the crop, not just through appearance. A direct sensor is much more suitable to measure plant health because it produces specific data. Thus, the team researched direct sensors specifically. All of the factors in the table above were considered in the decision making process.

The team then decided that from the given sensors in the detailed background, the best option is the X5000, due to its great versatility, relatively low price, accuracy, and how well suited it is for the groups needs. But, the team decided to continue the search for a higher quality sensor than the X5000.

The team focused on the UAS's sensing capabilities, and after much research, the Sequoia multispectral sensor ($3,400) from Parrot and MicaSense and the 2 Axis Gimbal for the Sequoia ($95) were chosen for the survey mission. The gimbal allows for a great turning radius with its 45 degree roll and pitch limits. The Sequoia sensor is designed and built for use on agricultural drones.[13] It is cheap, accurate, and versatile, weighs 0.24 lbs, and includes

[13] The team found that the Sequoia sensor works best on plants with low variation in height because it

an irradiance and multispectral sensor. The multispectral sensor features four bands: a 1.2 Mpx red camera, a 1.2 Mpx green camera, a 1.2 Mpx near infrared camera, and a 1.2 Mpx red edge camera, along with a 16 Mpx RGB reflectance camera. It also features a built in 64 gigabyte memory and is Wi-Fi enabled. It also contains a memory card slot to supplement the internal storage in the multispectral sensor. The additional irradiance sensor is mounted on the top of the UAV to collect data on current lighting conditions to refine and recalibrate measurements from the multispectral sensor. It also features an IMU enabled GPS device to geotag sensor readings and track the aircraft's current location. The X5000 does not have any of these additional functions and is much more expensive.

### *Dash Mission*

For the dash portion of the challenge, the team decided to monitor a farm for nitrogen streaking. The Andover Blueprints decided to apply the UAV in this way after speaking to actual farmers. The group spoke to a local farmer, and she pointed out that nitrogen streaking is a huge problem in the local area as well as across the country and can lead to the loss of an entire harvest. To detect nitrogen streaking in a large circular field, the UAV can use any of the following sensors: a multispectral sensor, hyperspectral sensor, or CCD/CMOS camera.

The group followed the same rigorous research, elimination, and comparison plan that was successful in finding a sensor for the survey mission. The team used a visual and multispectral sensor to detect nitrogen streaking. A RGB sensor on a drone is the simplest and most efficient way to detect these nutrient deficiencies and multispectral imaging adds a deeper understanding of the problem in showing the farmer surface nutrient content and chlorophyll contents. It was best for us to provide a single versatile multispectral sensor to make our product cheaper and easier to use, so the team decided to stick with the Sequoia multispectral sensor. For a visual camera, the Andover Blueprints ended up deciding between the Zenmuse X3 gimbal and camera ($459) and the GoPro HERO5 session ($299) plus a gimbal ($186). The group chose to use the GoPro because it is designed to be mounted on UAVs, is extremely ruggedized for the conditions of a farm, and can accurately complete the products missions in 4k at 30fps or 1080p at 60fps.

In conclusion, the aircraft, the Sequoia, and the GoPro make the product extremely effective. All of the missions allow farmers to quickly, easily, and efficiently transport equipment as well as sense imperative data points accurately.

can detect biotic stress when pests attack plants (per the survey mission.

### 2.3.2 Air Vehicle Element Selection

BluSkye coupled with a 55cc gas engine was an outstanding design for the UAV. The extended range, large payload capacity, and cost influenced the build of this platform.

**It is made of the following components:**

- BluSkye Airframe ($250.00)
- Tunigy TR-55 55cc Gas Engine 5.6HP ($232.46)

**It contains the following sensors and electronics (C3):**

- Micro-controller ($100)
- 900MHz data transceiver set ($135)
- Autopilot ($149.99)
- Multiplexer ($0.45)
- Lipo Battery Pack Charger ($8.50)
- Serial servo controller ($18)
- GENS ACE 450 mAh 11.1 25 C 3S1P Lipo Battery Pack ($5.29)
- IMU (Inertial Measurement Unit) ($40)
- GPS ($50)[14]
- GoPro HERO5 Session camera ($299)
- GoPro motorized gimbal ($186)
- 2 Axis Parrot Sequoia Stabilized Gimbal ($95)

**It requires the following support equipment:**

- Panasonic Toughbook PC ($320)
- Thrustmaster joystick ($50)

The team considered different takeoff and landing systems and recognized that wheeled landings minimize damage during landing and maximize ease of use during takeoff. It also increases the safety as the operator can launch the UAV from a safe distance.

The UAV uses the Sequoia sensor by Parrot and MicaSense. The data analysis that comes with it is valuable, and it is Wi-Fi enabled so transferring data is easy. It was chosen because of its small size, sunlight sensor, built in GPS, strong range, high resolution, and ease of use. It is attached to a gimbal built by Parrot. The sensor is designed for agricultural drones, so it is prepared to survive the conditions expected when growing crops. A GoPro HERO5

[14] Note that the GPS and IMU are only carried on the Logistics mission due to a lack of the Sequoia sensor

Session is used in the survey mission. It captures 1080p 60 fps video in high definition and comes in a both water and dust proof case, making it well suited for use on a farm.

The servo controller, battery, and data transceiver are all necessary for the functioning of the autopilot and the transmission of its data to the ground station computer. The multiplexer is necessary to put the safety pilot in control of the UAV should the autopilot fail. The Sequoia sensor features an IMU and GPS, but is not carried on the example logistics mission. Thus, a separate IMU and GPS were purchased to aid with navigation and positioning. All electronics, payloads, and machinery are housed either inside the additional cargo hold or the main fuselage of the UAV. Computer duster will clean out the components, which are already sealed off from grime by the hull. Finally, the maintenance plan provides added financial protection against issues with the UAS.

The cost of the bare airframe is $250.00. With the electronics, sensors, support equipment, and engine, the system costs $7,072.55.

### 2.3.3 Command, Control, and Communications (C3) Selection

When the team was deciding the structure of the C3 system, there were three distinct strategies taken into consideration: autonomous, semi-autonomous, or manual C3 systems. Each of these strategies requires a different set of hardware and operational costs. Here are the explanations of each strategy:

- Manual systems give the operator the greatest flexibility and control over the aircraft. This greater amount of control comes with a high cost, due to the need for more onboard sensors and telemetric hardware, as well as extra personnel. Manual control would consist of an operator or operators and a remote control. Manual control also increases the possibility of human error in the flight path. This altered flight plan will reduce efficiency and will require a more trained operator than an average farmer.

- Semi-autonomous systems fly with some element of human control and some element autonomous by utilizing a computer that executes a pre-programmed flight course. These systems allow for manual control in case of an emergency or when more freedom is needed. These systems retain some of the flexibility of manual systems, while greatly reducing the operational cost and increasing accuracy, efficiency, and ease of use.

- Autonomous systems provide for the least expensive and most accurate C3 system, however, and are somewhat flexible when it comes to mission execution. These systems fly themselves by executing a pre-programmed flight path in a flight computer without any human control, but still have the option to switch to manual control in case of an emergency. All cruise maneuvers have to be programmed into the flight computer, along with takeoff and landing.

The team ultimately selected the autonomous system because it offered the most robust solution. It gave us a pre-programmed takeoff and landing and also allowed us to fly an exact flight path. The autonomous system sometimes brings up the question of safety, but the ability to switch into manual provides a safe control method if issues arise. The aircraft will be flying autonomously along the pre-programmed flight path until the operator needs to switch to his or her remote control.

### *Selecting the Command System*

In order to implement an autonomous system, the ground controller has a Panasonic Toughbook PC ($320) outfitted with software to constantly monitor the UAV's autopilot movement and flight data. This computer is also connected to the joysticks that pilot the UAV during emergency manual flight. As the UAV continues its path, it relays flight information back to the operator through a data transceiver set. The team chose this command system due to its quick autopilot to manual transition time, ease of use, and ability to display in-flight information. As for the control system the team thought that although a tablet or RC remote would be a little easier for a farmer to learn in the beginning, it would by no means be able to match the flexibility, speed, and information that the Panasonic Toughbook provides.

### *Selecting the Control System*

There are two situations for the control system: one for missions with the Sequoia sensor and one for the missions without it.

Without the Sequoia sensor onboard, the Panasonic Toughbook PC will converse with the UAV's MHz data transceiver set ($135), micro-controller ($100), IMU ($40), and GPS ($50) for proper positioning. The data transceiver set and micro-controller work in tandem to relay the GPS and IMU's information to the ground station. This communications unit will also converse with the multiplexer ($0.45) and serial servo controller (SSC) inside the UAV's hull. The multiplexer is the piece of equipment that switches the UAV between autopilot and manual flight mode and directs the SSC ($18) to manage the movement of the ailerons and rudders.

With the Sequoia sensor onboard, the GPS and IMU are not needed, as they are built into the sensor itself. In this case, the Panasonic Toughbook PC will converse with the UAV's MHz data transceiver set, micro-controller, and Sequoia sensor. The data transceiver set and micro-controller work in tandem to relay the Sequoia's information to the ground station. This communications unit will also converse with the multiplexer and serial servo controller (SSC) inside the UAV's hull.

At launch, for all missions, the PC will send a signal to the multiplexer that will turn the UAV's autopilot ($149.99) on, thus disengaging the SSC from manual control. The pre-programmed flight plan will be executed thus giving full control to the autopilot. Unless the autopilot is disengaged, the SSC cannot be controlled manually. This feature is so that manual control is available in case a failure occurs with the autopilot system. This feature is also in place for the landing of the UAV. Although the UAV will land during normal operation with the autopilot, in case the autopilot fails, the UAV can land manually. To do this, the multiplexer re-routes the signal from the pre-programmed course to the joystick ($50) that is connected to the PC. The operator will take these controls and land the UAV on the dedicated landing strip.

### *Selecting the Communications System*

When selecting the communications system, it was mostly a question of ease of use, ease of setup, reliability, cost, and signal range of the data transceiver from the ground to the receiver on the UAV. Before choosing a radio video transmitter, the team calculated the maximum possible range between the ground station and aircraft. For this minimum range, for all missions, the assumption was made that the controller would be at the edge of the takeoff landing strip with the aircraft at the maximum possible cruising altitude of 400 feet (0.0757576 miles) at the opposite corner. The team calculated that the drone would be no more than 1.4 miles from the ground station.

If the ground station is at one edge of the field, the farthest the drone can be away is 400 ft above the opposite edge of the field. To calculate this distance, the team used the Pythagorean Theorem, setting up the sides of the triangle as $\sqrt{2}$ miles (the diagonal distance from the edge of the field to the furthest destination), and 0.0757576 miles (the maximum height): $\sqrt{2 + 0.0757576^2} = 1.4162$ miles.

With this calculation in mind, the team looked for a radio that had a long enough range so it could meet, and, hopefully, surpass this constraint. It also had to be robust enough for the pilot to reliably control the plane in case of an emergency. After looking in the catalog and on other external websites, the team decided to use the 900MHz High Range Data Transceiver Set from the catalog, as it was best suited for the purposes. It proved to be an economical and complete solution with a more than apt range of 6.3 miles and a cost of $135.

### 2.3.4 Support Equipment Selection

While choosing support equipment for the UAV, the Andover Blueprints considered how best to maximize the support equipment's usefulness while maintaining a low cost. The team decided to select minimalistic equipment that provided enough support for one UAV only. Given that the operation plan includes only one UAV, there was no need for any support beyond these options, and this strategy helped the team conserve the amount of money spent on support equipment.

The team chose a utility trailer, priced at $299, to provide necessary transportation of the UAV and other support equipment. This is the best option for the team's design because it was the least expensive and also has enough space inside to carry the UAV. The team included the Internal Combustion Flight Line Kit for $130 in order to recover from any engine malfunctions on the UAV that could happen while it is at the farm. This kit is not strictly necessary for the daily operation of the UAV, but if the UAV ever experiences malfunctions while on the farm, the kit will allow the UAV to be repaired immediately and continue with its operation, rather than requiring off site maintenance.

The support equipment and resulting cost was significantly abridged due to the team's business model. For example, there is no need for a generator, as farmers can charge the UAV's battery at their own homes, instead of having to charge it in the field.

### 2.3.5 Human Resource Selection

The Andover Blueprints' company consists of four major divisions: training, maintenance, marketing, and analysis. The training section is a 27 hour comprehensive training program costing $720 and is designed so that farmers can operate the UAS legally, safely, and efficiently. To ensure the success of this goal, the team chose to employ two Flight Trainers ($25 per hour for 10 hours), two Systems Trainers ($20 per hour for 7 hours), and two Safety Trainers ($20 per hour for 10 hours). The number of trainers is simply a reflection of the 100 customers that will need to be trained for the first year of operation and this number will increase over time. In this plan each trainer serves 5-10 customers per month depending on the time of year (see section 4.2.1 for more details). Using the skills that each of these individuals brings to the table, the company has designed a comprehensive plan for instructing operators on how to use the UAS. The flight trainer will instruct the farmer how to fly the UAV, by starting instruction on a very basic level and progressing to more complicated maneuvers later on. Then, the safety trainer will teach the operator how to control the drone safely and explain to the farmer the FAA rules and regulations. The team believes that since the majority of FAA regulations are concerned with safely operating a

UAV, hiring a FAA compliance trainer would be useless to customers. After this the systems trainer will give the farmer a complex breakdown of the specifics of the UAS.

Despite all of this training, the UAS may still break. In order to prevent farmers from worrying about this, the maintenance division was created. This division consists of one repair technician ($25 per hour), one electronic technician ($25 per hour), and one support systems technician ($30 per hour). The number of technicians is due to an estimated 5% yearly crash rate with 25 hours of work per crash as well as annual maintenance with 2 hours of work per UAS for most units, adding to a total of 325 hours of total work for the team. Although the UAV is very durable, there is a small chance that parts like the landing gear orienter may malfunction after repeated usage. In order to repair physical parts, the team employs repair technicians that can quickly fix damaged UAV parts. If the Sequoia sensor, which is essential for many of the missions, breaks, a repair technician will not have the necessary knowledge to fix it. So, if this happens, an electronic engineer will fix the sensor as soon as possible. Furthermore, even with an intuitive C3 design, a customer may break something, such as an antenna. To ensure that the drone is not limited by the durability of the controls, the Andover Blueprints will hire support system technicians that are trained to fix the C3 support equipment.

Finally, the analysis division is made up of one data analyst (costing $35 per mission– 1 hour of work) and two agricultural advisors ($40 per mission– 2 hours of work), and this division is responsible for helping farmers use the UAS to improve their profitability. The reason the team only employs three people for this division is that each mission will take 1 hour of data analysis and two hours of agricultural advisory, meaning that in the first year each employee will work around 960 hours per year, which is around 20 hours per week. Data analysts are essential to the company because they interpret raw data from the UAS, and then send it to agricultural advisers, who create a comprehensive plan that the customers can carry out to fix any problems they encounter.

### 2.3.6 Safety Components

The team recognizes a UAV's potential to injure people, damage property, and endanger livestock. Thus, countless safety features were utilized. The many issues, as listed below, may occur, so the team implemented the following components to produce the safest precision agriculture UAS on the market:

- **Ground Avoidance:** The following systems alert the UAV to increase altitude if they indicate that the system is flying below 40 feet between takeoff and landing:
  - Built in IMU in the Sequoia sensor (Provides current altitude)

  - Glonass GPS (Provides current location and approximate altitude)
  - Nikon range finder (Provides the UAV with exact current altitude; utilized especially for takeoff and landing to make adjustments to the escalation and deescalation of the aircraft)

- **Obstacle Avoidance:** The team chose to utilize a range finder called the LightWare SF11/C to determine if an object is in the direct path of the UAV because nothing can feasibly operate at the UAV's top speed. If an object is present in the UAV's path, the UAV takes a sharp turn until there is nothing in the flight path, and then corrects to the normal flight path. This will most likely never occur due to the use of LATAS.

- **Loss of GPS Signal:** The Glonass positioning system allows for references to cross reference with the main GPS and Sequoia GPS to ensure than a loss of GPS signal was nearly impossible.

- **Additional Safety Concerns:** The team built two databases into the system for obstacle avoidance and flight safety that significantly decrease the likelihood of the crash.

  - LATAS Ground (A "proprietary, 3D ground obstacle database [that] gives the drone operator unmatched visibility of trees, buildings, power lines and other hazards that could cause damage to the aircraft." This knowledge prevents collisions by allowing the operator to modify the flight path to avoid obstacles)
  - LATAS Air ("LATAS [Air] is the only platform that displays live, FAA radar feeds to US drone operators and real-time aircraft traffic in 128 countries." The system also shows all no fly zones, including warnings about forest fires and other disasters where UAV flight should be avoided. The Andover Blueprints' system automatically submits the flight plan to LATAS Air for safety prior to flight, which suggests any changes.)

## 2.4 System and Operational Considerations

The final objective function value was 0.7536. In order from highest to lowest, the values for the function's different parts were: 1.000 for the dash speed, 0.8973 for the survey time, 0.8513 for the additional missions, 0.8196 for the logistics weight, and 0.2000 for the business profitability.

In order to get these values, the team attempted to balance the objective function while minimizing the cost needed to obtain high values in all criteria. This was done because the function takes an average of all of the values, so the team decided that in order to maximize its value, all the individual components will need to be maximized as well. To achieve this goal, the team created a table of values for the objective function and saw which drone specifications were needed to get high function values. For example, it was decided that having a maximum payload weight of approximately twenty one pounds was large enough to carry significant objects such as irrigation system motors, but small enough that building a drone that met this specification would not cost too much. Twenty one pounds was also determined by the researchers to be the most viable and useful payload for a farmer. This is also one of the highest realistic weights a cost effective UAV can carry, with regards to the FAA's fifty five pound weight limit. The team designed a drone that could fulfill the team's specified requirements, without going too far over them. This way, the team did not spend extra money on a UAV flying at ninety knots or launching with more than fifty five pounds. Also, at a certain point, a difference of one changes the objective function so little that it is more efficient to save money on parts than to try and get the drone to fly for an extra few minutes or takeoff with twenty three pounds instead of twenty one. Such considerations kept the cost of the drone and its parts as low as possible while still keeping the objective function value high. But objective function value was only a single piece of the puzzle. Another key factor of the drone its safety. Unlike with the FAA regulations, the team thought that it was impossible to be too safe and thus dedicated lots of time and resources in order to achieve the team's own safety goals, which often surpassed that of the minimum requirements. For instance, the team's UAS uses a satellite array in tandem with real time FAA data to determine if any obstacles prohibit the drone's flight path and gives the drone time to avoid them. Innovations like these drove the team to make the UAV as safe as possible and create an optimal design for the drone that was both safe and efficient for farmers.

## 2.5 Component and Complete Flight Vehicle Weight and Balance

The total empty weight of the UAV is 33.595 pounds, and the maximum takeoff weight varies with the mission. For every mission, in order to find the center of mass of the entire UAV at maximum takeoff weight, the team split it into three components: empty airframe, payload, and power source. The moment and center of gravity calculations for the empty airframe are below. The datum point used for the fuselage station measurement is at the tip of the nose of the plane.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Airframe** | 21.87 | 596.61 | 27.29 |
| **Engine** | 28.15 | 164.96 | 5.86 |
| **900MHz data transceiver** | 25.59 | 0.64 | 0.025 |
| **Multiplexer** | 25.59 | 0.84 | 0.033 |
| **Autopilot** | 25.59 | 1.31 | 0.051 |
| **Serial servo controller** | 25.59 | 0.28 | 0.011 |
| **Micro-controller** | 25.59 | 0.56 | 0.022 |
| **Glonass Positioning System** | 25.59 | 0.56 | 0.022 |
| **LightWare SF11/C (120 meter)** | 0.00 | 0.00 | 0.15 |
| **Total Empty Airframe** | 22.89 | 765.76 | 33.464 |

Table 19: Details of Empty Airframe

The empty UAV has a center of mass located at 22.89 inches from the nose for all missions. The UAV's payload, power source, and the total weight data for each mission are below.

### 2.5.1 Logistics Mission

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **CPI motor** | 13.78 | 279.045 | 20.25 |
| **Inertial Measurement Unit** | 25.59 | 0.26 | 0.01 |
| **GPS** | 25.59 | 0.51 | 0.02 |
| **GoPro HERO5 Session** | 7.87 | 2.12 | 0.27 |
| **GoPro HERO5 Session Gimbal** | 7.87 | 2.68 | 0.34 |
| **Total Payload** | 13.63 | 284.62 | 20.89 |

Table 20: Details of Payload in Logistics Mission

The UAV payload has a center of mass located at 13.61 inches from the nose in the logistics mission. The UAV's power source data is below.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **GENS ACE Battery Pack** | 23.62 | 2.36 | 0.10 |
| **2c Gas mixed 30:1** | 23.62 | 10.87 | 0.46 |
| **Total Power Source** | 23.62 | 13.23 | 0.56 |

Table 21: Details of Power Source in Logistics Mission

The UAV power source has a center of mass located at 23.62 inches from the nose in the logistics mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the logistics mission.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Total Empty Airframe** | 22.89 | 765.76 | 33.46 |
| **Total Payload** | 13.63 | 284.62 | 20.89 |
| **Total Power Source** | 23.62 | 13.23 | 0.56 |
| **Total UAV** | 19.37 | 1063.61 | 54.91 |

Table 22: Details of Weight of UAV in Logistics Mission

In the logistics mission, the team's UAV center of mass at takeoff weight is located 19.37 inches from the nose.

### 2.5.2 Survey Mission

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Sequoia Sensor** | 7.87 | 1.89 | 0.24 |
| **2 Axis Parrot Sequoia Stabilized Gimbal** | 7.87 | 3.15 | 0.40 |
| **GoPro HERO5 Session** | 7.87 | 2.12 | 0.27 |
| **GoPro HERO5 Session Gimbal** | 7.87 | 2.68 | 0.34 |
| **Total Payload** | 7.87 | 9.84 | 1.25 |

Table 23: Details of Payload in Survey Mission

The UAV payload has a center of mass located at 7.87 inches from the nose in the survey mission. The UAV's power source data is below.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **GENS ACE Battery Pack** | 23.62 | 2.36 | 0.10 |
| **2c Gas mixed 30:1** | 15.75 | 317.835 | 20.18 |
| **Total Power Source** | 15.79 | 320.20 | 20.28 |

Table 24: Details of Power Source in Survey Mission

The UAV power source has a center of mass located at 15.79 inches from the nose in the survey mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the survey mission.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Total Empty Airframe** | 22.89 | 765.76 | 33.46 |
| **Total Payload** | 7.87 | 9.84 | 1.25 |
| **Total Power Source** | 15.79 | 320.20 | 20.28 |
| **Total UAV** | 19.93 | 1095.8 | 54.99 |

Table 25: Details of Weight of UAV in Survey Mission

In the survey mission, the UAV's center of mass at takeoff weight is located 19.93 inches from the nose.

Since all additional missions developed contain the same components, the tables containing the details of payload, power source, and weight of UAV are the same.

### 2.5.3 Dash Mission

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Sequoia Sensor** | 7.87 | 1.89 | 0.24 |
| **2 Axis Parrot Sequoia Stabilized Gimbal** | 7.87 | 3.15 | 0.40 |
| **GoPro HERO5 Session** | 7.87 | 2.12 | 0.27 |
| **GoPro HERO5 Session Gimbal** | 7.87 | 2.68 | 0.34 |
| **Total Payload** | 7.87 | 9.84 | 1.25 |

Table 26: Details of Payload in Dash Mission

The UAV payload has a center of mass located at 7.87 inches from the nose in the dash mission. The UAV's power source data is below.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **GENS ACE Battery Pack** | 23.62 | 2.36 | 0.10 |
| **2c Gas mixed 30:1** | 23.62 | 63.77 | 2.70 |
| **Total Power Source** | 23.62 | 34.72 | 2.80 |

Table 27: Details of Power Source in Dash Mission

The UAV power source has a center of mass located at 23.62 inches from the nose in the dash mission. Below is a compilation of all the UAV data for a calculation of the UAV's overall center of mass at maximum takeoff weight in the dash mission.

| Component | Fuselage Station (in) | Moment (inch-lbs) | Weight (lbs) |
|---|---|---|---|
| **Total Empty Airframe** | 22.89 | 765.76 | 33.46 |
| **Total Payload** | 7.87 | 9.84 | 1.25 |
| **Total Power Source** | 23.62 | 34.72 | 2.80 |
| **Total UAV** | 21.60 | 810.32 | 37.51 |

Table 28: Details of Weight of UAV in Dash Mission

In the dash mission, the UAV's center of mass at takeoff weight is located 21.60 inches from the nose.

## 2.6 Design Analysis

The aircraft, although capable of carrying more, has a maximum takeoff weight of 55 lbs due to the FAA weight cap. It is also able to fly at a speed of 146.8 ft/s (87 knots), which is the FAA cap for the UAV's velocity, and at an altitude of 400 feet, also a FAA restriction limit. Using the maximum weight the aircraft could fly at, which was provided by the UAV website, the team was able to calculate the lift coefficient of the aircraft:

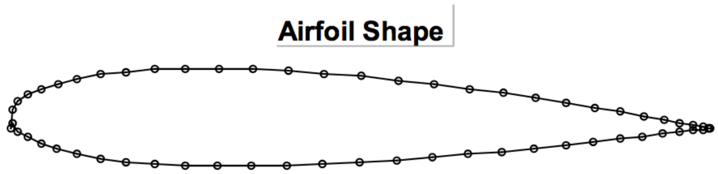
$$C_L = \frac{L}{0.5rAv^2}$$

Where $C_L$ is the lift coefficient, $L$ is the lift force in Newtons of the wings, $r$ is the air density in $\frac{kg}{m^3}$, $A$ is the wing area in $m^2$, and $v$ is the aircraft velocity in m/s.

BluSkye's maximum flying weight is 55 lbs, 24.95 kg, or 244.76 Newtons. The lift force provided by the wings must be equal to this, in order to allow the plane to fly. Therefore, the team estimated the lift force to be 244.76 N. The team was unable to accurately find the density of the air the aircraft would be flying through, so the team used the air density at sea level of $1.225kg/m^3$. The aircraft's wing area is $12.1ft^2$, or $1.125m^2$ (3 m by 0.375 m). To get $C_L$, the team used the aircraft's flight velocity of 146.8 ft/s, or 44.76m/s (87 knots). Once all of this data was inputted, the team calculated the lift coefficient of the aircraft to be 0.18, when the aircraft is at 0 degrees angle of attack.

Then, the team identified the lift coefficient of the wing, it was easy for the team to find the ideal airfoil type. The team decided to adapt the NACA 1714 wing as the airfoil of BluSkye. Below are the shape and the geometry of the airfoil.

NACA 1714




| x | y | x | y |
|---|---|---|---|
| 1.00000000 | 0.00000000 | 0.06688076 | -0.02981375 |
| 0.99732594 | 0.00054430 | 0.09531723 | -0.03673816 |
| 0.98918293 | 0.00216096 | 0.12816795 | -0.04258625 |
| 0.97570782 | 0.00480173 | 0.16507457 | -0.04727388 |
| 0.95704464 | 0.00838986 | 0.20563567 | -0.05075100 |
| 0.93339324 | 0.01282488 | 0.24941097 | -0.05300743 |
| 0.90500754 | 0.01798810 | 0.29592565 | -0.05407425 |
| 0.87219308 | 0.02374814 | 0.34467519 | -0.05402109 |
| 0.83530405 | 0.02996562 | 0.39513037 | -0.05294989 |
| 0.79473965 | 0.03649638 | 0.44674271 | -0.05098644 |
| 0.75093995 | 0.04319315 | 0.49895017 | -0.04827082 |
| 0.70438117 | 0.04990574 | 0.55118314 | -0.04494834 |
| 0.65557059 | 0.05648031 | 0.60287061 | -0.04116194 |
| 0.60504108 | 0.06275844 | 0.65344641 | -0.03704686 |
| 0.55334532 | 0.06857699 | 0.70235548 | -0.03272802 |
| 0.50104983 | 0.07376944 | 0.74906005 | -0.02831964 |
| 0.44872883 | 0.07816931 | 0.79304560 | -0.02392678 |
| 0.39695794 | 0.08161590 | 0.83382656 | -0.01964783 |
| 0.34630781 | 0.08396184 | 0.87095175 | -0.01557691 |
| 0.29733771 | 0.08508193 | 0.90400946 | -0.01180559 |
| 0.25058903 | 0.08488197 | 0.93263217 | -0.00842301 |
| 0.20657907 | 0.08330640 | 0.95650082 | -0.00551446 |
| 0.16579483 | 0.08034322 | 0.97534869 | -0.00315837 |
| 0.12868722 | 0.07602547 | 0.98896467 | -0.00142228 |
| 0.09566578 | 0.07042820 | 0.99719596 | -0.00035847 |
| 0.06709383 | 0.06366129 | 1.00000000 | 0.00000000 |
| 0.04328440 | 0.05585831 | | |
| 0.02449678 | 0.04716277 | | |
| 0.01093383 | 0.03771328 | | |
| 0.00274001 | 0.02762941 | | |
| 0.00000000 | 0.00000000 | | |
| 0.00273810 | 0.00637035 | | |
| 0.01091857 | -0.00371729 | | |
| 0.02444670 | -0.01318304 | | |
| 0.04317014 | -0.02192173 | | |

Figure 10: NACA 1714 Airfoil Geometry

Once the team identified the NACA 1714 airfoil, the team came up with a complete analysis of it with JavaFoil, an online aerodynamics tool. Below is the graph JavaFoil produced of the wing's $C_L$ values vs Alpha, the angle of attack.

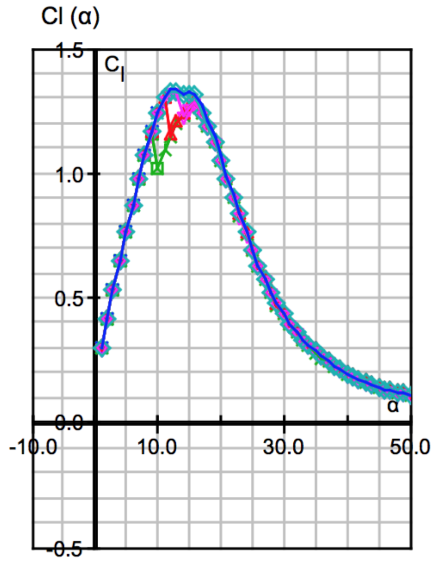



Figure 11: Lift Coefficient Graph

From the graph, the team discovered that the stall angle of 1714 is around 11°. To calculate the $C_d$ and the $C_M$ values of the aircraft, the team put the 1714 airfoil under a simulation provided by JavaFoil. It is able to come up with a list of $C_d$ and $C_M$ values against their respective angle of attacks (Alpha). The team cut the table off after the critical angle of attack of around 11°, as provided by the chart below.

| Alpha | $C_L$ | $C_d$ | $C_M 0.25$ |
|---|---|---|---|
| 0 | 0.183 | 0.014 | -0.014 |
| 1 | 0.298 | 0.013 | -0.016 |
| 2 | 0.415 | 0.014 | -0.017 |
| 3 | 0.530 | 0.015 | -0.019 |
| 4 | 0.644 | 0.016 | -0.021 |
| 5 | 0.754 | 0.018 | -0.022 |
| 6 | 0.859 | 0.020 | -0.024 |
| 7 | 0.957 | 0.022 | -0.025 |
| 8 | 1.054 | 0.023 | -0.027 |
| 9 | 0.949 | 0.051 | -0.010 |
| 10 | 1.022 | 0.057 | -0.011 |

Table 29: List of $C_L$, $C_d$, and $C_M$ Values vs Angle of Attack

The team was also able to identify the pressure coefficient distributions at different angles of attack on top of $C_L$, $C_d$, and $C_M$ and generate the Flow Field of the 1714 airfoil under three angles of attack: 0, 5, and 10 degrees. The graphs are below.

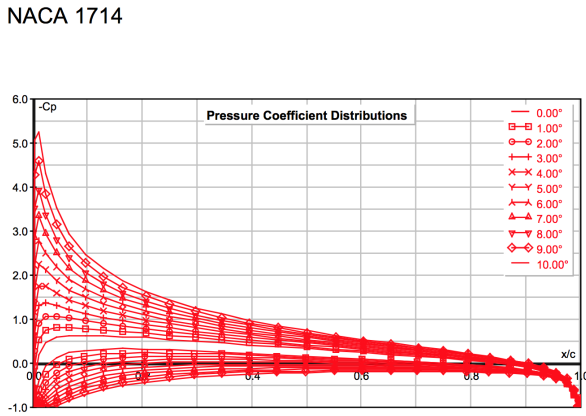



Figure 12: Pressure Distributions of 1714

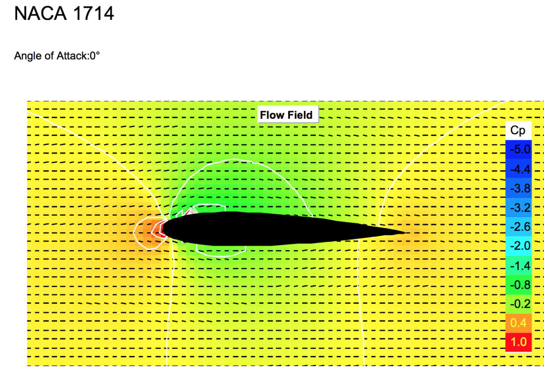



Figure 13: Flow Field at 0° of Attack

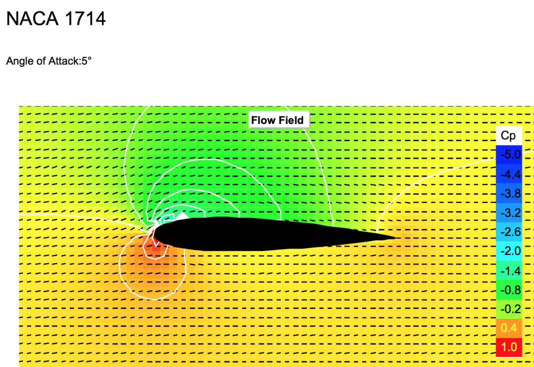



Figure 14: Flow Field at 5° of Attack

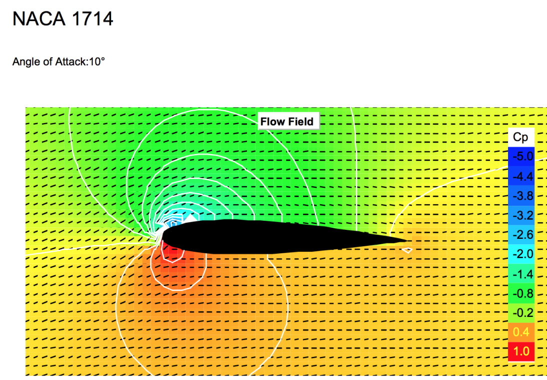



Figure 15: Flow Field at 10° of Attack

## 2.7 Operational Maneuver Analysis

The team then calculated the minimum turning radius the aircraft will have, given the maximum bank angle, to prove that it can make the planned turns in various missions: 1320 ft (logistics), 264 ft (survey), and 162 ft (dash). To do this, the team split the lift force into two components, the vertical component, which is equal to the weight of the aircraft $W$, and the horizontal component ($L_h$), which is the portion of lift that provides the centripetal force. After that, the team looked at the equations used to calculate $L_h$. The total lift force formed the hypotenuse of a right triangle, with $L_h$ being the opposite side with respect to the bank angle $\theta$, and $W$ being the adjacent side. Therefore, the team can calculate $L_h$ by using the Pythagorean Theorem:

$$L_h = \sqrt{L^2 - W^2}$$

Since $L_h = \frac{mv^2}{r}$,

So, $\frac{mv^2}{r} = \sqrt{L^2 - W^2}$.

So, $r = \frac{mv^2}{\sqrt{L^2 - W^2}}$

Since $m$, $v$, and W are given, in order to minimize $r$, the team realized that they had to maximize $L$. According to the calculations in section 2.6, $L$ is maximized when the angle of attack is approaching the stall angle of 11°, resulting in $C_L$ approaching 1.05. Since in each mission the UAV is flying at different speeds, the team calculated $L$ in each case scenario. When $v = 40$ knots, $L = 306.41$ N; when $v = 50$ knots, $L = 478.58$ N; when $v = 87$ knots, $L = 1449.40$ N. From the equation derived above, the team then calculated the minimum $r$. When $v = 40$ knots (survey), $r = 188$ ft; when $v = 50$ knots (logistics), $r = 131$ ft; when $v = 87$ knots (dash), $r = 115$ ft.

The minimum turning radii of the aircraft in all cases (188 ft, 131 ft, 115 ft) are under the planned turning radii the team called for (264 ft, 1320 ft, 162 ft). Therefore, the aircraft will be able to fly according to the team's plan.

## 2.8 CAD Modeling

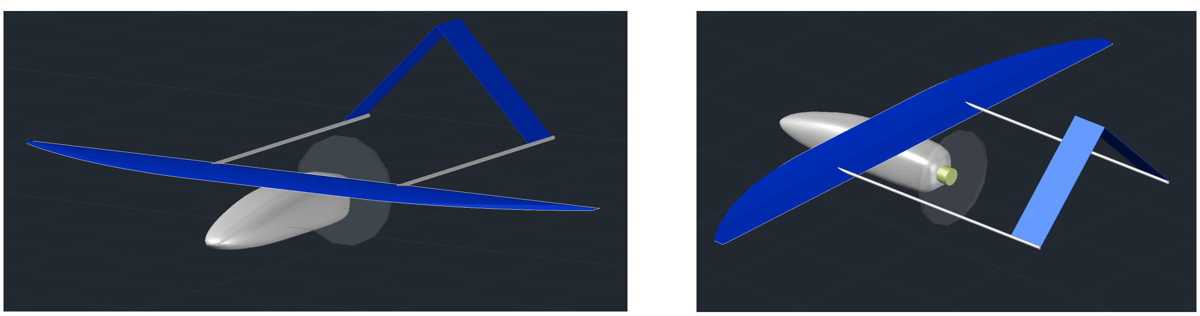
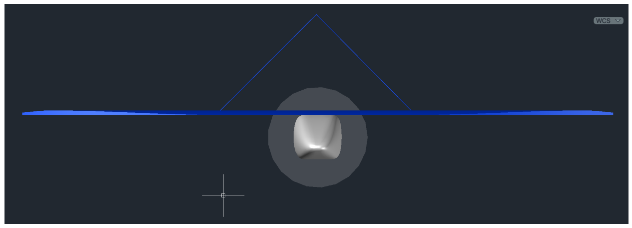
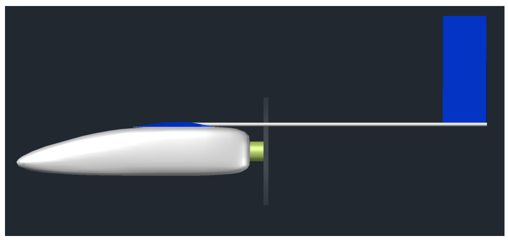


Figure 16: BluSkye From Different Viewpoints

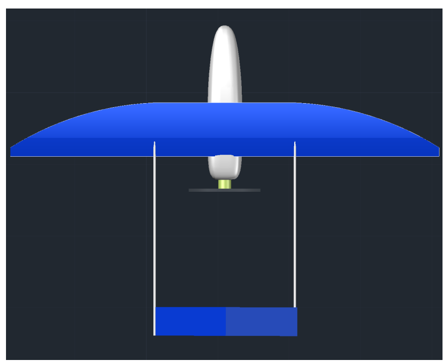
## 2.9 Three View of Final Design



(a) XZ View of Airframe



(b) YZ View of Airframe



(c) XY View of Airframe

Figure 17: Three View of BluSkye

Dimensions of BluSkye:
- Airframe Wingspan: 118.11 in (3.000 m)
- Airframe Length: 75.59 in (1.920 m)
- Airframe Height: 28.66 in (0.728 m)

# Chapter 3

# Document the Missions

## 3.1 Logistics Mission

The logistics mission requires a UAV to transport a payload of 10 lbs without recharging batteries or refueling. The Andover Blueprints chose to deliver a center pivot irrigation motors as the payload for this mission. These motors are crucial to the large sector of the farming industry that uses center pivot irrigation (CPI) systems to supply its circular crops.

CPI motors are the most important part of a CPI system because their function is to rotate the large booms and towers around the field in order to deliver pesticides and water. If any of the motors fail or aren't working at maximum efficiency, the resulting irregularities in movement can result in nitrogen streaking, anhydrous streaking, uneven irrigation, or other damages to the crop. The goal of the team's solution is to be able to address the problem as fast as possible because instead of driving a vehicle to drop off a CPI motor, a drone can be deployed to expedite the transportation process.

But because dropping off the motor is a one-way payload, the team needed to fill the payload on the way back. A natural solution to that problem is to have the farmer fill the return payload with the malfunctioning motor. This dual-payload system allows resources to be allocated efficiently and accelerates a tedious process for the farmer.

### 3.1.1 Theory of Operation (Example Logistics Mission)

To set the stage for the logistics mission, imagine that the center pivot irrigation system on the farm begins to slow. The farmer, recognizing this, heads out into the field to fix the system. After recognizing that a motor is broken, he or she can inform a colleague at the farmhouse to prepare a drone for delivery, rather than driving to and from to pick up the fresh motor for replacement.

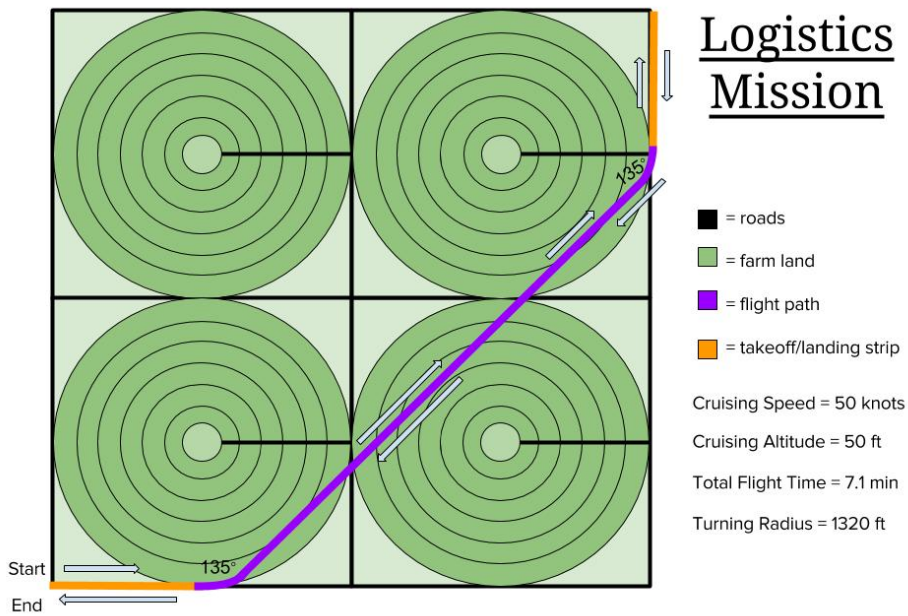



Figure 18: Logistics Mission Flight Plan

The UAV will take off from a short airstrip near the field, take the shortest route to its destination 1 mile away, land, have its CPI motor removed, then have the payload replaced with the damaged motor, and finally return to its starting location. In order to complete this mission, there needs to be at least two human resources (two trained farmers), one at the drone's starting location (Farmer-1) and one at its destination (Farmer-2). The ground control station is at the edge of the takeoff strip.

To start, Farmer-1 will place the UAV on its dedicated takeoff strip (the service road used for trucks and machinery) and then execute the five point safety check mandatory per the Andover Blueprints' software. He or she will then initiate the flight plan using the ground station. Farmer-1 will watch to make sure he or she maintains visual line of sight, while also being ready to switch to manual control using the ground control station in case of an emergency or failure. The UAV will then follow the flight plan and land on the service road near the perimeter of the field. Next, Farmer-2 unloads the functional motor and refills the payload with the damaged motor. The UAV will finally take off and follow the flight plan back to its starting location, where it will land back on the initial service road and refuel to be prepared for any future missions. This process is designed to be compliant with FAA regulations and allows farmers to have flexibility over the destination of the UAV.

Visual line of sight is maintained by the operator throughout the execution of the mission as the drone takes off, flies, and lands autonomously. The turns that the UAV makes follow the curve of the field until the nose is pointed towards the destination. This helps align the UAV and make sure that its autonomous landing is exact. The whole mission itself will take about 7.6 minutes, out of which 2.1 minutes is flight time and 5.5 minutes is loading and unloading the UAV's payload. The team's calculation for flight time is shown below.

The take off angle (∠A) is 10°. Since the cruising altitude is 50 m ($\overline{BC}$), $\sin 10 = \frac{50}{\overline{AB}}$, where $\overline{AB}$ is the path that the UAV travels from the ground to the cruising altitude. Thus, $\overline{AB} \approx 287.9$. To find $\overline{AC}$, the Pythagorean theorem must be used. Thus, $\overline{AC} = \sqrt{(\overline{AB})^2 - (\overline{BC})^2} = \sqrt{287.9^2 - 50^2} \approx 283.6$.

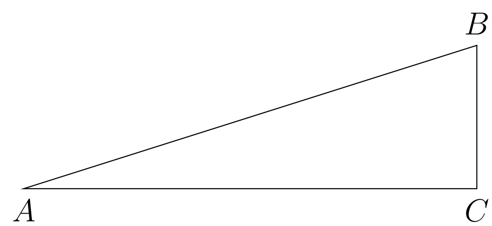



Figure 19: Escalation for Logistics Mission

Now, the time taken while climbing and descending can be figured out. Since *speed* $= \frac{dist.}{time}$, then $time = \frac{dist.}{speed}$. So, $time = \frac{287.9ft}{50knots} = \frac{287.9ft}{5063.43ft/min} \approx 0.06min$.

To find the time taken while cruising, the same formula as above must be used. However, the distance while cruising has not been calculated. To find that, since it is known that the total distance of the trip is 1 mi and a distance of $2 \times \overline{AC}$ is covered while reaching cruising altitude, the total distance while cruising is: $5280ft - 2(283.6ft) = 4,712.8ft$. So, $time = \frac{4712.8ft}{5063.43ft/min} \approx 0.93min$. Thus, the total flight time one way is $2{\times}0.06 + 0.93 = 1.05$ min. Therefore, the total flight time both ways is: $1.05{\times}2 = 2.1$ min total.

The overall purpose of the mission is to provide farmers with a way to expedite the process of delivery. By delivering a functioning motor straight to the farmer and allowing him or her to send the broken motor back, the farmer does not have to leave the field in order to address mechanical failures. Not only does this save a lot of time, it saves the gas that the farmer's truck would use, allows mechanical malfunctions to be addressed faster, and gives farmers more time to tend to their crops— time, which would otherwise be spent driving back and forth to gather materials.

### 3.1.2 Logistics Mission Design Considerations

Because of the nature of the engineering design process, the Andover Blueprints went through many iterations of designs and, especially for the logistics mission, many payloads. At first, the team thought that using the UAV to drop off tools or the farmer's lunch would be an effective use of payload space, but it is rather foolish to buy a $9,000 drone for the purposes of transporting tools and food. The payload was then changed to soil samples, but even this was not efficient enough. The team regarded this new payload as inefficient for two reasons: 1) soil samples are a one-way payload; therefore, fuel would not be economized, and 2) soil samples take time to analyze, so having a drone expedite the process makes no difference, and also farmers can always bring soil samples back with them at the end of their work day.

CPI motors have the highest failure rate out of all of the components on a CPI system. This is because of the corrosion that occurs when the pesticides and insecticides seep into the housing of the motor during operation of chemigation. Thus, the best course of action is to replace them, and it happens to be that these motors are small and light enough for a drone to carry. After narrowing the payload choice down to a CPI motor, the team decided to fill the return payload with the damaged motor in order to maximize payload efficiency. This dual-payload system allows the team to distribute resources methodically and expedite the transportation process.

As outlined in 3.1 & 3.1.1, the designed mission is beneficial to farmers because they don't have to leave the field in order to address mechanical malfunctions. Time is saved, the gas the farmer's truck would use is saved, and infestation can be addressed much faster. Additionally, on center pivot irrigation fields, the circular design forces farmers to drive around the field rather than driving across with a tractor.

In order to make the team's UAV capable of meticulously completing the survey mission and dash mission, the Andover Blueprints had to compromise on the payload weight for the logistics mission. This was a result of the team selecting an airframe that can hold a moderate amount of payload, but can travel very fast. This airframe was chosen to make sure that the team's UAV would be well-rounded. That said, to balance this compromise, the team developed a strong link between the dash and logistics mission to ensure an advantage for the farmer. If a farmer discovers that a CPI motor has been disabled for some time, the logistics mission can be executed to deliver the new motor, but then the dash mission can be executed immediately after to see if the hardware malfunction caused any nitrogen streaking or other damage to the crop (see section 3.3-3.3.2).

## 3.2 Survey Mission

The survey mission is intended to be a scanning mission to encourage the team to maximize the endurance of the aircraft. The team chose to scan for crop health to meet the survey mission requirements using the Sequoia sensor. Crop health is a valuable statistic which the Sequoia sensor scans for by sensing biotic stress, nutrient deficiency symptoms, and more. The farmer then connects the Sequoia and uploads its data to Andover Blueprints for analysis.

The team chose the Sequoia sensor by Parrot and Micasense because it is built for use on agricultural drones, can detect water stress, symptoms of nutrient deficiencies, biotic stress, identify problems in the field, estimate crop yield, and much more. A irradiance sensor is mounted on top of the UAV to measure lighting conditions to refine and recalibrate measurements from the multispectral sensor. It features an IMU enabled GPS device to geotag sensor readings and track the UAV's current location. Because GPS readings can be off by up to two meters, even in open areas, the team implemented a second hyper-accurate Glonass positioning system, which cross references with the Sequoia sensor's GPS to build a precise model of the field and avoid obstacles. These features make it an excellent choice to scan for crop health on the survey mission (see section 2.3.1 on further sensor selection details).

Additionally, the team researched multiple cameras to use for the survey mission. Cameras were judged based on the following factors: affordability, small size, versatility, toughness, 60+ frames per second, 1080p+ resolution, and low weight.

(a) Sequoia Multispectral and Sunlight Sensor


(b) GoPro HERO5 Session

Figure 20: Survey Mission Main Payload

The team narrowed the options down to a GoPro HERO5 Session (0.27 lbs) and the Wi-Fi Action Sports Camera (0.34 lbs) due to the fact that they represent just a few of the small pool of cameras built for rugged farm conditions. Both record in 1080p and 60fps and have a low weight and size. Although the Wi-Fi action sports camera claims to film in

HD, after analyzing footage, it was determined that the quality failed to meet the team's standards. The team chose one of the most reliable and well tested drone cameras, which was certified on a member's RC drone: the GoPro HERO5 Session[1].

Ultimately, this mission consists of the Sequoia sensor and the GoPro, being used to scan for crop health and film respectively. The team built this mission to maximize endurance, while also considering overlap of the sensor, crop application, and general market application in the modern day world.

### 3.2.1 Theory of Operation (Example Survey Mission)

To conduct the survey mission, a farm chooses to utilize the BluSkye to scan for crop health. Assuming the proposed operator is a licensed UAV pilot, and BluSkye is registered with the FAA, the farm can choose to conduct the mission. To begin, the operator must first enter a flight plan. Once this is complete, it is cross referenced with the LATAS database to ensure proper safety and the proper adjustments are made. The survey mission flight plan, as seen below, consists of 25 smaller 1 mile by 1 mile fields each with 4 center crop irrigation fields. This is because according to satellite imagery and the team's mentors, center crop irrigation fields are typically in groups of 4. The scanning pattern below includes this.

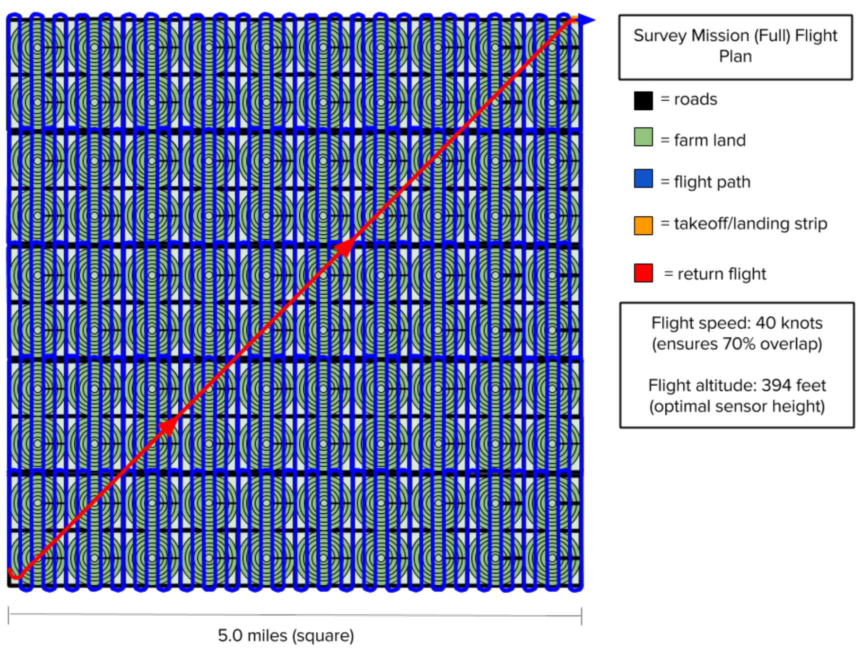



Figure 21: Survey Mission All Fields Flight Plan

[1]The GoPro also features internal stabilization which is crucial to maintain a steady image. This is coupled with a gimbal to produce excellent footage

Each one of the twenty five squares consists of the following flight plan:

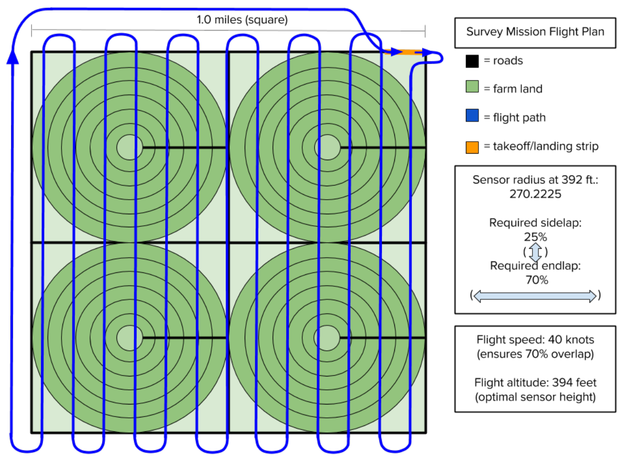



Figure 22: Survey Mission One Field Flight Plan

Having entered this flight plan, the operator conducting the survey mission will mount and engage the following payload on the BluSkye: a Sequoia multispectral sensor (0.24 lbs), a two axis Parrot Sequoia stabilized gimbal (0.4 lbs), a GoPro HERO5 Session (0.27 lbs), and a GoPro HERO5 Session Gimbal (0.337307 lbs). The fuel tank is filled with 20.182693 pounds of fuel. This accounts for a 54.9883702 lb total UAV, including the airframe, engine, electronics, sensors, and gimbals.

The operator now places the UAV on the takeoff and landing strip and engages the BluSkye, and turns on the GoPro and Sequoia sensor. The Glonass positioning system and the Sequoia's GPS now cross reference the current location of the UAV with the proposed location in the flight plan. The operator makes the appropriate adjustments, and then initiates takeoff.

Once the UAV is in the air, it spends the next 6 hours, 32 minutes, and 47 seconds conducting the mission before landing on the takeoff strip. 18.6 lbs are used, leaving about 1.5 lbs extra for emergencies. The derivation of the flight time is below:

$$25\, fields \times (5280 \times 10 + 528\pi \times 5) + \sqrt{2(5 \times 5280)^2} + (5 \times 5280) = 1591080.353\, feet$$

$$1591080.35 \div 5280 = 301.340976\ miles\ covered$$

$\sqrt{2(5 \times 5280)^2}$ is the return trip length

$(5 \times 5280)$ is the length traveled alongside the field in the full flight plan

$$301.340976\ miles \div 46.0312\ mph = 6.546450581\ hours$$

$$6.546450581\ hours = \text{6 hours 32 minutes 47 seconds}$$

Figure 23: Survey Mission Flight Time Calculations

When the UAV returns and safely lands autonomously at an angle of ten degrees, the farmer detaches the Sequoia sensor and GoPro HERO5 camera. The devices then connect to the Panasonic Toughbook PC via either Wi-Fi or cable, and the data and video from the flight is submitted to the Andover Blueprints' secure web portal to be analyzed, so the farmer can get a proper conclusion on which specific areas require attention, increased analysis, or treatment. The IMU & GPS readings from the Sequoia sensor and Glonass positioning system are overlaid to tag and provide location for the GoPro footage. The purpose of the mission, to capture crop health, has been fulfilled, as 25 square miles of plants has been scanned and videoed at 1080p 60 fps to determine their well being.

### 3.2.2 Survey Mission Design Considerations

When farmers are able to accurately measure crop health, it allows them to understand the current growth rate, reevaluate their farming practices, adjust pest control, and increase yield. The choice of farm, method of collection, and ease of use are all key factors when designing a mission to collect details on current crop health. The team considered the ideal situation to collect data while creating a versatile UAS for a farmer.

Although many applications were suggested, the team, working with the mentors, eventually decided to either scan for moisture detection or crop health. Both data points often vary across a field, so utilizing a UAV to scan for them would allow a farmer to adjust their farming practices accordingly across a field and therefore maximize yield. After extensive research, the practical uses of a crop health mission became increasingly clearer. Farmers can understand issues in their growing cycle and overlay scans over periods of time to recognize prevalent problems. Thus, the team decided that crop health would be scanned for on the survey mission.

Applicability to the market is a crucial part of both building a strong product and business strategy. After researching the market, the team discovered that only the top 20% can afford to buy the BluSkye. The top 20% of farmers typically employ minimal people and maximize profit by using center crop irrigation to produce a higher yield. Furthermore, center crop irrigation farmers typically produce potatoes, soybeans, corn, and wheat along with cotton and rice. Rather than having the farm choice affect the mission design, the team allowed the market to determine the applicability of the mission.

The team's UAS presents a unique and cost effective solution to allow a farmer to scan for crop health. It only employs one person to operate for under 480 minutes at a cost of $10.39 per hour (the average wage of a farm worker), so $83.12 in total. The additional analysis cost brings the total mission cost to about $160. Tractors scanning with smaller sensors operate at a maximum speed of 30 miles per hour, and a typical pace between 5 and 15 miles per hour. Other methods, such as individual scanning and satellites, cost unaffordable sums. Thus, this UAS presents a time and cost effective solution for a farmer when scanning for crop health. It also only requires fuel and a human operator, with little to no outside help. Farmers can therefore collect key data on their own with little resources involved.

As it relates to overlap, the team read the Sequoia user manual several times to understand a way to maximize efficiency.

| | Time between shots | | | |
|---|---|---|---|---|
| Height (m) | 5 m/s | 10 m/s | 13 m/s | 20 m/s |
| 30 | 1.1 | 0.5 | 0.4 | 0.3 |
| 40 | 1.4 | 0.7 | 0.5 | 0.4 |
| 50 | 1.8 | 0.9 | 0.7 | 0.5 |
| 60 | 2.2 | 1.1 | 0.8 | 0.6 |
| 70 | 2.6 | 1.3 | 1.0 | 0.7 |
| 80 | 2.9 | 1.4 | 1.1 | 0.74 |
| 90 | 3.3 | 1.6 | 1.2 | 0.8 |
| 100 | 3.7 | 1.8 | 1.4 | 0.9 |
| 110 | 4.1 | 2.1 | 1.6 | 1.0 |
| 120 | 4.4 | 2.2 | 1.7 | 1.1 |
| 130 | 4.8 | 2.4 | 1.9 | 1.2 |
| 140 | 5.2 | 2.6 | 2.0 | 1.3 |
| 150 | 5.6 | 2.8 | 2.2 | 1.4 |

Key:
- In red: the multispectral sensor and the RGB sensor cannot be activated.
- In blue: the RGB sensor cannot be activated.
- In green: all the sensors can be activated.

Figure 24: Endlap Chart and Max Speed & Altitude

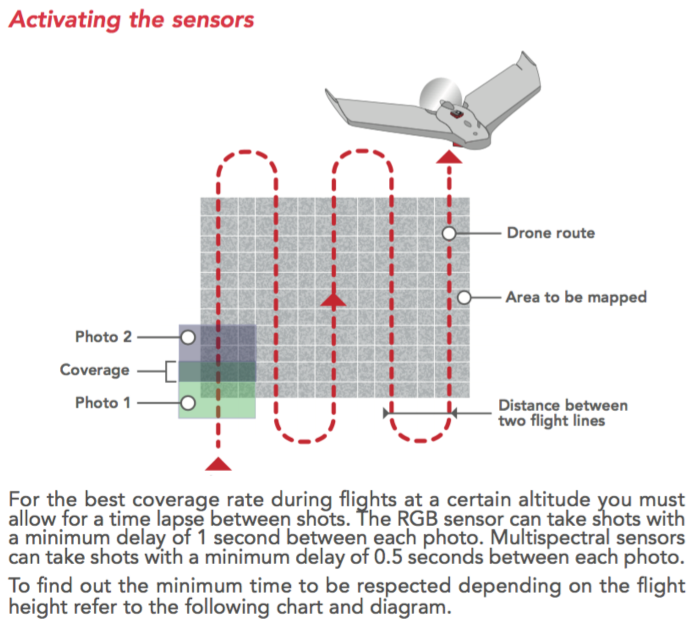



Figure 25: Sidelap and General Flight Plan Specifications

Per this information, the team needed to limit the speed of the plane to 40 knots at a height of 120 meters (394 feet) to ensure over 70% endlap. The team assumed 25% sidelap per the other diagram and ensured to accommodate this in the flight plan. Ultimately, the team properly accounted for the necessary overlap to produce data for the farmer.

The team decided that a fixed wing plane is the only UAV design that is capable of accomplishing the logistics, survey, and dash missions. Extended flight time was ideal, so to reach that requirement, it became obvious that the mobility of a rotorcraft would have to be sacrificed for a fixed wing design to extend the range. However, fixed wing aircraft are faster, so this design increased the effectiveness of the dash mission. Thus, few compromises were made in the designs of other missions for this mission.

## 3.3 Dash Mission

The Andover Blueprints brainstormed logical, useful, and efficient applications that met the dash mission requirements through extensive online research and conversations with the mentors. The team contacted multiple farms and farmers through email, phone, and in person to acquire a more comprehensive perspective.

The team's proposed dash mission is quickly scanning a large area of farmland for nitrogen streaking with the Sequoia multispectral sensor and GoPro HERO5 Session. The mission scans for plant nutrients, chlorophyll, and the color of the crop. Nitrogen deficiency is a huge issue, caused by uneven spreading of fertilizer and rain washing away nutrients. It causes an estimated 6.98 billion dollars in damages per year, as entire fields affected by uneven nitrogen spreading must be cleared. This can be detected earlier and fixed by re-spreading fertilizer or treating it effectively with the proper chemicals. All these irregularities found by the UAV show up as discolorations and altered values on the final image. These discrepancies can then be analyzed by the team's trained data analysts and agricultural advisors once the customer uploads his or her data on the Andover Blueprints' secure web-portal that ensures complete data privacy.

### 3.3.1 Theory of Operation (Example Dash Mission)

To conduct a dash mission, one farm worker must be present at the takeoff and landing strip. The BluSyke is then filled with 2.76 pounds of fuel. A farmer attaches the Sequoia Sensor (0.24 lbs), a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), the GoPro HERO5 Session ($299.00), and the GoPro gimbal ($186.00). These components add up to a four-pound payload.

Below is a diagram of the dash mission's flight plan:

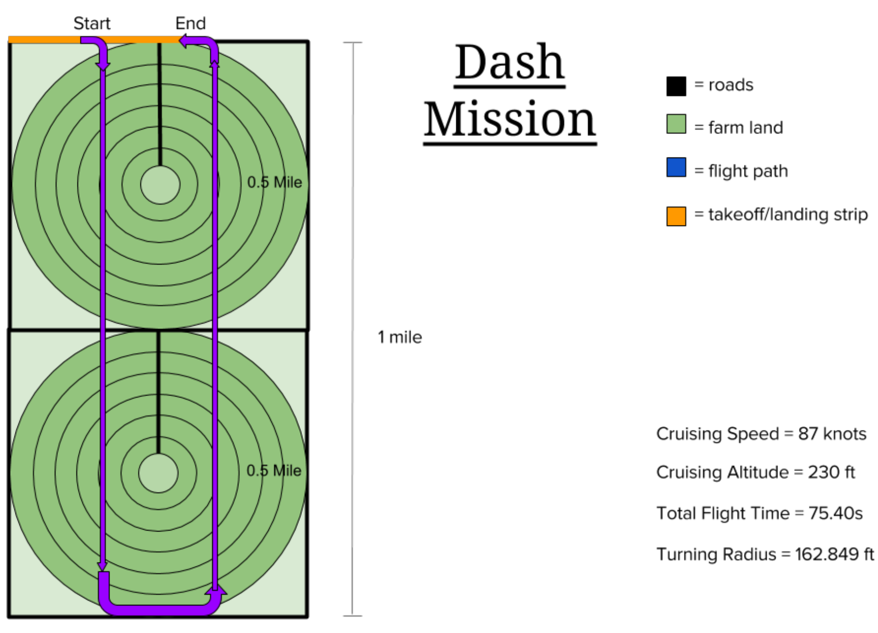



Figure 26: Dash Mission Flight Plan

A farm worker places the drone on the takeoff strip, which is a nearby service road for large farm equipment and trucks. One farmer stays at this position on the runway during the execution of the mission. He or she will maintain visual line of sight along the 1 mile flight route[2] and be ready to use the Thrustmaster joystick and Panasonic Toughbook, which are at the ground control station (at the edge of the takeoff strip), to take over manual control of the UAV in case of an emergency. The farmer also sets the flight plan (see above) and starts the UAV, Sequoia, and voice activated GoPro. The farmer, who is not employed by our company, will close out the 3-5 minute preflight setup by conducting the computer based five point safety check as well as a test of all the drone's parts and controls. The UAV will fly completely autonomously from one edge of the circular field to the other, turn, and return back on a route next to the original. It will collect data with the Sequoia multispectral sensor and the GoPro. The Sequoia will measure the amount of nutrients and chlorophyll in the crop, and the GoPro will sense a discoloration in the plants, which can be analyzed by computer algorithms. The UAV completes the mission in only 1.25 minutes and lands on the same landing strip it took off from. Refueling is done once the UAV lands. The derivation of flight time is below:

Time Taken During an Entire Turn: $\frac{162.849\pi ft}{8810.37 ft/min} = 0.05806852857\ min$

Time Taken During Straight Line: $\frac{5280 ft}{8810.37 ft/min} = 0.59929378675\ min$

The flight plan works as follows. The UAV takes off in a negligible amount of time, takes a right 90° turn and goes in a straight line for 1 mile. Then, it makes a 180° turn and flies back for 1 mile in an adjacent path to the first one to maximize the sensed area. Finally, it makes a left 90° turn and lands in a negligible amount of time on the same farm road it took off from. Thus, in total, the UAV traverses the 1 mi straight line twice and makes two entire turns. Therefore, the two above numbers are multiplied twice and then added to one another: $2 \times 0.025\ min + 2 \times 0.6\ min = 1.25\ min$.

After the drone lands, the farmer will turn off the UAS and plug the drone into the ruggedized laptop to upload the data to the Andover Blueprints' secure web portal. The customer will then wash off, quickly disassemble into 4 pieces, and store the UAV. The collected data is sent to the data analysts ($35 per hour) and business decision experts ($20 per hour) (agricultural advisers) in the company headquarters. The data is processed by computer algorithms, which analyze collected images and cross reference them with geotags

[2]Visual line of sight is defined as "a line from an observer's eye to a distant point." Due to the fact that the team is operating on flat farmland with corn plants, the operator will always be able to meet the FAA definition of visual line of sight since the human eye can see objects 2.9 miles away.

for analysis. With the company's rapid decision support system, the farmer can then take immediate action based on the UAV's findings.

### 3.3.2 Dash Mission Design Considerations

Because of the nature of the engineering design process, the Andover Blueprints went through many design iterations. The team spoke extensively to its agricultural mentors to inspire ideas. This gave the team a good idea of what farmers need from a UAS such as the one the group was designing. This made the UAV viable on the market and let the team list multiple possibilities for the dash mission.

The group considered carrying the following: soil samples, tools, emergency medical equipment, dead plants, or pest traps across farmland, quickly monitoring the following: crop health, moisture, or nutrients, or scanning a vertical swath of the field to discover early nitrogen streaking. The members began by deliberating over missions and ruling out options that would not be realistic or benefit the customer. While deciding, the team made sure to keep in mind that it had chosen to focus on corn fields. The first mission in the list was ruled out because transporting light items (two or more pounds) is not reasonable in a real farm as such items can usually be carried or driven around and the logistics mission already carried a payload. The team also deemed it would be better to expand on the data collection capabilities of the UAS, as this is the focus of our company: data and decision support. The crop health option was also deemed unfit because at 230 feet, the UAV would only cover a maximum of 651.40 feet by 1 mile with no overlap, which is not an option.

Finally, the group decided to scan for signs of nitrogen streaking due the effect it had on the targeted market, and extensive research into the quickness by which it could be scanned. Quickly recognizing nitrogen streaking can prevent long lasting damage so a farmer can save a crop, or indicate to a farmer to give up on a field if the damage has ruined the harvest. This was a complicated issue to fix and the team took it on to provide a thoroughly useful product for the industry.

To realize this mission, the Andover Blueprints had to consider the height and speed of the UAV so the Sequoia sensor can cover ground quickly with a required 70% endlap to collect reliable data even though the visual data from the GoPro is the primary indicator. The sensor would have to be flown at below 35 knots, or the minimum speed of the UAV, in order to ensure the proper endlap. However, the purpose of this mission is to detect if nitrogen streaking is present, and to consider the severity of it, rather than to exactly detect the location of it. Thus, the team collects impartial Sequoia data and cross references it with data from the GoPro. This allows the farmer to understand if the issue is present, understand the general location of if it is, and know the severity of the problem. If the farmer intends to treat the nitrogen streaking by recognizing that the severity if treatable, a survey type mission can be conducted to precisely determine the location of the issues across the entire field.

## 3.4 Additional Farm Missions

The team designed thirteen additional agricultural missions that make BluSkye extremely versatile and useful:

- **Moisture Detection:** This mission was designed to determine the moisture content of the crops and soil. Using the Sequoia sensor, the drone flies over a plot of land and calculate the moisture content. According to farmers, moisture content in the soil varies across a field, so having a drone calculate it is extremely helpful because it allows the farmer to customize irrigation equipment based on the climate.

- **Infestation Detection:** This mission was designed to discover infestation in a field using the Sequoia sensor's powerful infrared technology. This allows a farmer to detect increased infestation and deploy pesticide and/or pest traps as necessary, thus maximizing yield and minimizing damage early on.

- **Harvest Yield Estimation:** To calculate harvest yield, a program is downloaded to the Sequoia sensor that allows it to count plants and size/number of product then calculate estimated harvest and yield to monitor over the years and predict income for that season depending on the plant. The Sequoia sensor is calibrated for that specific crop and then the drone is flown over the field. This identifies and numbers the crops over a desired field size for a desired and calibrated crop type.

- **Creating VRA Maps:** Variable-rate applicability maps are a way of showing the strength of nutrient uptake in a field. To create them, the UAV employs the Sequoia sensor to create a map that indicates where plants may need increased nutrients, are diseased, or lack sufficient water and/or sunlight.

- **Time-Series Animation:** A time-series animation map is a series of images that can be stitched together to find differences between healthy and unhealthy plants over a period of time and can be used to show changes in the crop and reveal any trouble spots or opportunities for crop management. By launching the drone with the Sequoia sensor attached, the UAV can compile a time series animation to help farmers see which crops are unhealthy, so they can remedy the situation.

- **Creating Reflectance Maps:** Creating reflectance maps allows farmers to create maps based off of the crops' light reflectance, and this helps them see what areas in their farms need attention. As a result the maps will help farmers increase yields, cut costs, and increase business profitability. The drone is launched with the Sequoia sensor attached to scan the fields to develop this map.
- **Biomass Detection:** The drone is launched with the Sequoia sensor attached to find biomass in crop residues in order to produce energy. This allows the farmer to reduce disposal costs and pollution, increases energy independence, and helps protect ground and surface water from poisons and excessive aquatic plant growth in order to make their farm more eco-friendly.
- **Scouting Fertile Land:** Farmers often buy more land than they plan to use in one year. However, as they grow and prosper, they utilize land that initially goes unused. Seeking out the areas that have greater nutrients and better soil can allow farmers to make smarter choices about where they plant specific crops each season. The Sequoia sensor is capable of measuring surface nutrients and moisture content of the soil; therefore, land can be scanned by the drone, using the NiR and visual lenses, in order to discover the ideal place to grow crops.
- **Water Drainage Maps:** In many places, the most fertile soil also has the most water retention. Although some of this retention helps crops grow, too much water can cause crops to stop growing or even die. So, it is necessary for farmers to monitor the water drainage of their fields to make sure that there are no risks to crop growth. The Andover Blueprints' Water Drainage Maps mission will help farmers avoid this problem by scanning fields for in-ground and above-ground water and allowing farmers to see where drainage equipment may be necessary.
- **Plant Height Detection:** Plant height can be an excellent indicator of crop vigor and growth and can give farmers an estimate of the dry weight of the crops. Since it is a essential statistic for farmers to know, the team designed a mission where the UAV scans the crops height while accounting for things such as the ground's slope. Farmers will be able to use the data collected to find any areas of poor growth and remedy the situation as well as estimate dry mass.
- **Emergence Uniformity:** Crop emergence is important to keep track of on a farm because it can be indicative of many other problems such as moisture contents of the seed zone and planting depth. So, by measuring how quickly and crops grow, farmers

can identify spots that are germinating slower than normal and use that knowledge to combat the issue preemptively so that they do not lose any crops in their infancy.

- **Canopy Cover:** Often times, farmers must make decisions about how they use their land. Though there are some standard factors to this like the distance between rows of crops, a lot of a farmer's land usage is subject to the size and shape of their fertile property. As a result some of the spatial decisions are simply guesswork. With the canopy cover mission farmers can scan their crops and see how much of the space they are actually using to its full potential and how much is being wasted. Then, using this data, they can revise their planting plans for the next season to maximize the area in which they plant their crops.

- **Weeds Detection:** This additional mission is intended to allow the farmer to seek out the specific areas with large amounts of weeds. Instead of employing hundreds of workers to comb the fields in an effort to eliminate weeds and invasive plants, the drone can be flown over to scan for hot-spots of growth. The farmer can then send employees out to specific parts of the field to target large invasive growths. Many farmers do not realize how bad their weed problems are until harvest time comes, so being able to scan for specific yield damaging invasions proves invaluable.

Every additional agricultural mission helps farmers gather data that they would not be able to with the team's other agricultural missions, and thus are all unique from one another because the missions all serve different purposes. That said, each mission utilizes the survey mission flight plan (see Figure 24/25) as a basis. Thus, each flight is conducted at 394 feet, 40 knots, for 7 hours 5 minutes, with the Sequoia sensor (0.24 lbs), a 2 Axis Parrot Sequoia Stabilized Gimbal (0.4 lbs), GoPro gimbal (0.34 lbs) and a GoPro HERO5 Session Camera (0.27 lbs).

Throughout the entirety of these additional agricultural missions, there is a minimal amount of manpower used. The first and most important person involved in this process is the farmer, who will be on standby in case any aerial intrusions or obstacles appear. In this case, the farmer will simply take control of the drone and guide it to a safer area so that no damage is done to either the intrusion or the UAV. The length of each flight varies upon the mission, but since the farmer is not being paid by the Andover Blueprints, the average mission time is irrelevant to the cost of manpower. After the UAV has collected data during the mission, it can be sent to a data analyst, who can compile all the raw data into a readable form. Due to the fact that data analysis is mainly compiling data rather than interpreting it and that the process is heavily augmented by computer programs, the team expects this process to take no more than one hour per mission. This costs the team

$35. The only other people involved in the missions are the agricultural advisors. Since the problems that farmers encounter are generally similar (for example, a pest infestation), the advisors will have a general template on how to fix each agricultural problem. Although the specific details might change, there are only so many ways to efficiently fix an irrigation leak. So, the team assumes that it will take no more than two hours per mission for an agricultural advisor to draft a plan for action for the farmer to use, and this will cost $40. That makes the total manpower cost for one mission $160, including the amount the farmworker is paid.

Because these missions are similar to the survey mission, no compromises were made in the process of designing these missions. Thus, both the three main missions and the additional agricultural missions are executed to the highest degree of precision and quality.

## 3.5 Safety Procedures

The following safety components have been implemented[3]:

- LATAS Ground and Air to secure flight plan
- Inertial measurement unit
- Downward facing range finder to determine current altitude
- Forward facing range finder to detect obstructions
- Glonass positioning system and standard GPS

**Loss of Signal from Pilot**

Although the system is constantly on autopilot, the pilot can always take over. If the pilot loses connection with the UAV, the UAV flies to the determined landing point via the cross referenced GPS coordinates and executes the landing sequence safety. The entire area that the UAV may have to fly over to return to the landing strip is scanned by LATAS Ground and Air to determine a proper return path and prevent collisions.

**Loss of GPS or Navigation Signal**

The likelihood of a loss of GPS signal is heavily unlikely due to the Blueprints' two layer failsafe mechanism; however, the team added a separate positioning system to ensure that this was not a possibility. A combination of two separate satellite networks (GPS and Glonass) ensures that signal will never be lost. However, in the near impossible event of a loss of all navigational signal, the UAV cross references the current turns and last known

[3] See 2.3.6 for information on these decisions

location with the planned flight plan and LATAS database to safely guide the plane back to the landing strip. In the unlikely event of a lack of calibration and the UAV not being able to return, the system will turn in a direction that lacks both roads and obstacles such as power lines (per Google Maps and the LATAS database), and initiate a glide to a belly landing.

**Loss of GPS and Pilot Signal**

The same response occurs in this situation as in the loss of just one of the signals.

**Obstacle Avoidance**

The team implemented LATAS Ground and Air to provide crucial obstacle avoidance that allows the operator to check the flight plan with known obstacles. Additionally, the UAV always flies at greater than 50 feet unless on the logistics mission. Few trees on farmland are that height, but if there is an object of that height on the logistics mission, the UAV will sense it using the rangefinder and take a hard turn until there is nothing in the UAV's path. Once the UAV sees nothing in the direct flight line, it will recorrect onto the original flight path. This properly prevents the UAV from hitting obstacles. Because the UAV is flying at greater than 200 feet for all other missions, there is no chance that it will hit anything because there is nothing of that height. If there were any obstacles, the LATAS database would have alerted the operator and would be avoided ahead of time. LATAS cross references with the FAA database, so there is no chance of hitting a plane. All missions are conducted on the farmer's property, so there is a low chance that a collision with another drone will occur. Because these procedures are automatic, they are consistent and always occur midflight with or without signal, with the exception of an emergency glide.

After extensive research, the team realized it could not utilize either Intel Realsense or a similar system such as FlightAutonomy from DJI because the UAV would be flying too fast. Both systems operate at a maximum speed of 22 mph and can sense objects as far as 15 meters ahead. Considering the UAS flies as high as 45 m/s during the dash mission, or as low as 20 m/s on the survey mission, these systems would be useless. Due to fact that sonar is neither applicable nor available, the team chose to utilize a range finder to determine if an object was in the direct path of the UAV. Nearly any fixed wing vehicle will have to stall to be able to use typical obstacle avoidance systems.

### Additional Safety Concerns

- **Landing/Takeoff:** The team recognizes that the likelihood of the aircraft's impact with obstruction vastly increases during takeoff and landing. Thus, the team implemented a downward facing rangefinder, which is cross referenced with the IMU to indicate the aircraft's current altitude. This creates increased precision during flight and allows the UAV to maintain altitude.

- **Five point safety check:** Prior to takeoff, the system executes a five point safety check which ensures safety during flight and checks the following:

  1. The status of the engine
  2. The height indicated by the downward facing rangefinder
  3. The presence of obstacles in the flight plan
  4. The presence of nearby aircraft in the flight plan
  5. The presence of a visual line of sight between the operator and the aircraft throughout the trip.

After it is found that all of these systems are working and the flight plan is accurate, the operator can initiate the autopilot.

# Chapter 4

# Document the Business Case

## 4.1 Patenting Your Idea

Due to the fact that the UAS qualifies as a machine, the company needs to file for a utility patent in order to protect its idea from intellectual theft. After the team did an in depth search to find out if the UAS system was patentable, the team found no results that were the same as the Andover Blueprints' UAS, which means the probability of the patent being accepted is high. In addition, the UAS is a summation of both premade and company made parts, so it will qualify as a single invention and thus be patentable as specified by USPTO regulations. However, in order to make sure of this, the company needed to do a patent search. This will cost $300 because the business qualifies as a "small entity" since the team will only employ around 30 people, and has no legal obligation to sell the patent to another larger company. After the patent search has been finished, the fee for the actual patent examination will be $360. These fees, combined with the small entity electronic utility patent filing fee of $70, make the total cost of obtaining a patent $730. Then, after 3 years, the team will be charged a fee of $800 for a small entity patent. The team can file this patent without employing a patent attorney, because the team's adviser has experience in patent applications and will guide us along the way.

The team also connected with an experienced patent lawyer to understand the actual process for filing a patent. The lawyer, Mr. Winslow Taub, specializes in patent law and was able to provide the team with an extensive background on filing a patent and issues that may arise. In order to file for a patent, a set of specifications and 20-22 claims must be submitted to the US Patent Office. Specifications include drawings, writings, diagrams, images, etc. and would detail the BluSkye's airframe along with the implemented sensors, fuselage, and payloads, in addition to writings detailing the "invention" that was created. Claims are one sentence "claims to fame" that cover the key components or uses of this invention that the team hopes to patent. For example, a claim covering the uses for the survey mission might be:

"A fixed wing drone aircraft that couples:

(a) A multispectral sensor with an HD camera attached to a gimbal to provide an individual with clear imagery and scans in order to indicate
(b) A Wi-Fi enabled multispectral sensor and a Wi-Fi enabled HD camera attached to the aircraft to upload data to a separate computer entity allowing immediate analysis following airborne data collection.
(c) A snakelike flight plan featuring back and forth turns across an agricultural plot of land with data collection through a multispectral sensor in order to provide an individual with data concerning the status of crops."

Despite being based off of current airframes, this system is easily patentable because the primary basis of the inspiration (the Aerohawk) is not patented. Thus, with pro bono assistance from the patent lawyer, claims and specifications would be submitted as a new and unique design because existing components are combined into a new unparalleled design featuring novel ideas.

## 4.2 Market Assessment

Agriculture has been the target field for a variety of new products claiming to help increase crop yield through data. Two notable contenders are satellites and airplanes, but due to their costs and inaccuracies, no other technology stacks up against the agricultural UAV. Satellites can cost up to $20 per acre and aircraft photography can cost $15 per acre, and even then the data gathered is still full of inconsistencies. Plus, after the data is gathered, it is given to farmers without any analysis, which is useless unless the farmer knows how to analyze complex data.

With low upkeep costs, often just costing that of fuel, as well as precise data gathering tools, any farmer would be wise to choose a UAV over other means of technology. In addition, large scale customers can purchase several of our UAVs to efficiently detect essential data to make vital decisions about their operation. And, many farmers do. They buy so many agricultural drones that agricultural UASs make up 80% of the commercial drone sales. So, there is quite a large market for agricultural drones, and thus numerous competitors, despite the high barriers for market entry. As such, the agricultural drone market has split into two groups: the cheap but ineffective UAS's and the expensive but versatile ones. Unsurprisingly, the range of costs for agricultural drones is wide with a low being around $300 and a high being around $25,000. The Andover Blueprints' company is attempting to bridge this gap and become the medium cost provider to the drone market, so it can reach the untapped market of farmers who want a powerful multipurpose tool but cannot pay $20,000 for one. The team's UAS captures this market perfectly because it currently costs $9665.69, placing it more than $4,000 lower than the nearest agricultural drone with similar capabilities. Despite its low cost, the Andover Blueprints' UAV can perform more missions than many of its more expensive competitors. For example weed, biomass, and infestation detection, as well as livestock monitoring. Also, the Andover Blueprints' drone has better physical capabilities than more expensive competitors. For example, similar drones are limited to a maximum speed of 60 knots, whereas the team's UAV can go up to 87 knots, a limit only due to FAA regulations. Also, with a 2 hour flight time, the Andover Blueprints' UAV can outlast most competitors, with their average flight time being around an hour.

However, this is just the market for purchasing drones. Many companies have farmers pay for a service in order to have someone else fly a drone over their fields. The main benefit to this is that it saves time for the farmer, but it is overpriced, with a single mission consisting of all the farmer's land costing around $525 depending on the service provider and size of the land photographed. If a farmer buys the team's UAS instead, he or she will be able to do as many missions as he or she wants, for one low monthly cost of $468.75.[1]

So, with all of this considered, the team projects that its UAS will become the standard choice for high quality agricultural drones, due to its physical durability and its sensor versatility. Both of these factors enable customers to collect more data about their farms than they could with the team's competitors. Also, the market for agricultural drones themselves will likely increase, seeing as it is consistently outclassing competitors such as satellite imaging in both accuracy and usage cost. As a result, the team believes that the Andover Blueprints' drone will be able to beat the competition.

### 4.2.1 Company Timeline

#### Year 1 Company Timeline

- Day 1- The company starts getting investors in order to obtain initial capital.
- Day 7- The team begins creating the patent application.

[1]See section 4.4.3 for details.

- Day 20- The team obtains a working location to house all data analysts, trainers, agricultural advisors, and mechanics.
- Day 21- The company begins hiring workers for maintenance, training, and data analysis.
- Day 25- Drone production will begin.
- Day 30- The team will begin selling drones and providing additional services to customers with ample time for farmers to prepare for the growing season.
- Day 32- The team will file their patent application, while paying relevant fees for doing so.
- Day 101- The team will meet a 20 drone sale quota.
- Day 170- The team will meet a 30 drone sale quota.
- Day 239- The team will meet a 20 drone sale quota.
- Day 308- The team will meet a 15 drone sale quota.
- Day 377- The team will meet a 15 drone sale quota.

The standard UAS sale quota is 20 drones and it is assumed that day 1 is January 1. The team projects that drone sales will vary, with most sales occuring right before and during the growing season. For the first quota, it is expected that Day 101 will be under the quota simply because it is a new company, and has not had time to get the public attention needed to draw in customers. However, day 101 aligns with the beginning of the planting season and thus the need for an agricultural UAS rises, so the company still expects to sell at least 30 units. Day 102-170 covers the majority of the growing season, so the sales are estimated to be 10 units higher than the normal sales. Day 171-239 covers the end of the sales boom and into the "dry season" where drone sales decrease dramatically because the growing season has ended. So, the team expects these factors to essentially cancel out, and that the standard 20 units, will be sold. After the growing season has completely ended, sales will definitely decline, making the quotas for days 240-308 and 309-377 much lower than the standard drone sale quota. This cycle will repeat for the first 5 years of the company, but around 50 extra sales will be made each year as the company becomes more publicly known, thus bringing in more customers.

## 4.3 Cost/Benefits Analysis and Justification

In order to increase business profitability, the team decided to find a niche in the market and then do everything possible to corner it. After much deliberation over which part of the agricultural UAS industry was the most undeveloped, one of the team's members noticed that there was a rift between extremely cheap drones and expensive but exceedingly durable ones. Cheap drones, although easier to sell to the common farmer, is a highly developed industry with many well known competitors dominating the market. Therefore, the team decided to avoid making one of these drones. Instead, the team wanted to become the low cost provider for durable drones, a market that is almost nonexistent as of the making of this project. By doing this, the team can sell to farmers who want an agricultural UAV to help them with their work, but are not willing or able to pay $20,000 for one. To do this, the team attempted to create a drone body that costed no more than $2,000 and had a high payload capacity, speed, and flight time so that customers can perform a wide range of missions. With these requirements, the team would be able to find a drone that maximizes the minimum requirement parts of the objective function, and still be sold at a low cost. The ultimate business goal was to sell the drone at $13,000, so that the team's drone would clock in at $3,000 less than its nearest competitor. After extensive research was conducted, the team's drone was created with a fixed wing design and with a 55cc gas motor because of its relatively low cost and high durability, thus helping the team accomplish its goal. Furthermore, because the team decided to create its own drone, it was able to choose its own sensors to attach, an option that may not have been possible had the team bought its drone. Since the team knew it would have to find its own drone, it researched a wide range of sensors, eventually deciding on the Sequoia. Choosing the Sequoia was quite possibly the easiest decision made, since the Sequoia had all of the capabilities needed to finish the specified missions,and costed less than its competitors, namely the X5000. The Sequoia sensor costed $3,400, which made the total cost of the core UAV components equal $4,000, giving the team a large budget to spend on training, C3 and safety equipment, and a video camera to make a 25% profit on the UAV and only charge $13,000 per unit. From this moment onward, the team created and utilized a versatility function to determine if a part was worth including in the overall system. It was quite a simple yet profound tool, giving outputs by simply dividing component cost by the number of missions utilized, and then dividing one by that number. The higher the versatility function value, the more cost effective the component. For example, the autopilot was used in all of the agricultural missions, and only costs $149.99. Its versatility function value is around .079, which may seem small at first, but is actually an exceedingly high output for the function. This made autopilot a must have for the UAS, and thus made it easy for the team to a lot necessary money for it. After running all of the proposed parts through the function, the team decided on the ones mentioned in section 2.3.2. Once the team had determined all the core parts of the UAS it turned its attention to safety. Because customer safety was a high priority of the team, it dedicated a $1,500 budget to procuring the safety measures that can work to help ensure the safety of all those involved. One such measure was the implementation of Latas Ground and Latas Air which provide real time data to the drone so that it can avoid any flying objects such as planes or even other drones. Also, the drone was equipped with pre-programmed procedures and the parts necessary to follow them in the unlikely event that it should lose connection with the farmer for any reason.[2]Even with these additions the total UAS cost was still around $3,000 under the preferred budget, which made the Andover Blueprint's UAV a plausible solution to many more farmers than originally anticipated. The end price of the UAS is $9,665.69, which still fits into the market niche that the team is trying to corner.

$9,665.69 may seem like a big investment at first glance, but it is definitely worth it for full time farmers. According to the USDA, around 80% of farms make the majority of their income from off farm sources, but these farms only account for 12% of all farm sales. For these businesses, buying an agricultural UAS is a waste of money, because the cost of the UAS is higher than the cost in time in resources to simply do the work manually. This is not the case for the largest farms, however, which produce 88% of the farm sales and typically makes a net profit of over $100,000 annually, according to a recent survey from Iowa State University. So, due to the drone's cost of around $9,665.69, it is necessary for the team to focus on selling to the owners of the largest farms in the U.S., who have the farm revenue to buy the UAS. This means that the team's agricultural drone market has approximately 600,000 customers. Although these targeted customers can afford it, in some cases the drone costs 15% of their annual income. As bad as this may seem, the drone will actually more than pay for itself over the course of a few years by utilizing its data to help farmers increase their annual crop yield dramatically.

One such ability is the drone's mission to detect pests. Assume for the sake of this example that, with the help of the team's agricultural advisors, only 5% of the harvest's crops are destroyed by pests. This is a reasonable number seeing that the pest control sensor only works when the actual crop has already been damaged, but sensitive enough that only a small portion of the crop must be damaged before pest detection. Studies disagree on exactly what percent of crops are destroyed by pests annually, but the consensus seems to be around the 20% mark. Using this number with the data from a USDA study that said

[2]See section 2.3.6 for details.

that an average of 118.5 bushels of corn were harvested per acre, it is clear that the actual number of crops originally planted is 148.1 bushels per acre. Had the farmers been using the team's UAS (thus reducing crop pest damage to 5% of crop yield) they would have harvested 140.6 bushels of corn per acre, which is a 15% increase in crop yield and therefore an equal percent increase in profit.

Another helpful mission that the UAS can perform is the weeds detection mission. Often times farmers believe that if they simply apply weed remover to their crops 2-3 weeks after corn crop emergence, they will minimize the damage that weeds have on their crops. Studies have proven this to be false, with weed damage still causing roughly 15% of corn to be lost per acre. Naturally the weeds are in a handful of concentrated areas. With the help of the Andover Blueprints' UAV, farmers can locate these areas and concentrate herbicides there, thus reducing both waste and the environmental impact. This will cause an increase of 20 bushels per acre, or a 10% increase in corn crop yield. These are just two missions out of many that the team's drone can do, and these two missions have already increased corn crop yield per acre by 25%, thus making the drone pay for itself and then some over the course of one year.

## 4.4 Additional Services

The Andover Blueprints' company, although mainly selling high quality drones, also provides a wealth of extra services to maximize the amount the consumer benefits. These services are UAS training, data and agricultural analysis, and maintenance. None of these services are required for the consumer to use, but many are very helpful and highly recommended for increasing farm production and taking care of the UAS.

### 4.4.1 Training

One of the most important services the company offers to its customers is UAS training. This training makes use of the training division's UAS flight and safety experts[3] to give new customers a 27 hour comprehensive learning plan. As any UAV pilot will tell you, learning how to fly a drone is no easy task. In order to ensure that potential buyers do not shy away from UAS agriculture, the company includes the $660 training cost within the cost of the UAS. So, anyone can learn how to use a UAS when buying the team's UAS. The training program shows customers how to safely pilot the UAV, gives them a course on understanding the mechanisms of the drone, and teaches them how to deal with any emergencies that may

[3]See section 2.3.5 for more details.

arise while the UAV is in flight. This course will more than prepare customers to pass the FAA Remote Pilot Airman Examination. Also, the training includes special lessons from the safety trainer, who will teach customers things like the line of sight rule and prepare them for the knowledge section of the Airman Certificate Examination, seeing that the drone qualifies as a commercial UAV. But, in the unlikely event that the customer does not pass the necessary examinations or just feels like he or she needs a continuation of their training, the farmer can request more lessons.

### 4.4.2 Maintenance

Accidents happen. Whether a customer accidentally crashes a UAV or the drone simply needs a regular tune up, some maintenance will inevitably be necessary. Because of this, the company strongly encourages customers to buy an insurance policy for $81.25 per year on their UAS. This service is even necessary in some territories that have changed or are changing their guidelines to make drone insurance mandatory. The policy works much like car insurance, where every month a customer will pay a small amount, regardless if the drone has been repaired or not that month. Thus, if the UAV does malfunction or simply needs regular maintenance, the insurance policy will cover any necessary costs. This is both economical on the part of the buyer and the insurer. From the buyer's perspective, many of the parts on the UAV are sensitive and expensive when bought individually. So, if a UAV crashes or a malfunction does occur, replacement parts and specialized repair labor will total to a very large cost on the farmer. The team estimates that one physical UAV crash will consist of some wing and engine damage, which will take 25 hours to repair fully and the labor will cost $625 in labor. A sensor malfunction will consist of faulty or broken circuitry and will take 15 hours to repair and $375 for labor. A support systems breakdown will consist of either physical or circuit damage and takes 8 hours to repair with a cost of $390 for labor. Also, it was concluded that in an accident, both the UAV and the sensors would need repair, so the total cost of one accident will be $1,000. This number is so high that its maintenance cost is more than sixteen years worth of insurance without accounting for parts, making the insurance plan far superior for customers than a pay-as-it-breaks plan. And as icing on the cake, the insurance plan will also cover any regular maintenance that a UAV might need. On the insurer side of things, this system works because it distributes risk of a crash, and therefore cost, over a large amount of people. Additionally, because the UAV is automatic, unless there is a safety concern and the operator must take over, the team does not anticipate many crashes, making the risk of having to pay the maintenance bill relatively low. And, as more people join the service, the amount of insurance income to pay for any potential accidents increases, thus, "distributing the risk" of crashes and the cover a greater population. As for the regular maintenance, it is estimated that this will only cost $50 on a three to four year cycle and simply needs to be taken out of the system's reserve as needed. It is due to that fact that this plan needs at least 25 customers to pay into the system for it to be profitable for the company, but since the insurance plan is the most economical maintenance option possible for customers, the team does not predict that this limitation will be a problem.

### 4.4.3 Data Analysis

Although the Andover Blueprints' UAV can carry large payloads, its main features are its Sequoia sensor and GoPro camera that can help the farmer get critical information to help increase crop yield. The UAS is an extremely powerful data solution, so data analysis is essential for most of the missions. Seeing as the team expects the farmers to use the UAS for this purpose, having a pay-as-you-go data analysis service seems inefficient and costly for customers. In order to solve this problem, the team offers a monthly subscription service for data analysis and agricultural advising. This subscription based approach also happens to provide a flow of revenue for the team's company rather than a one time fee. It is projected that each individual mission will require 3 hours of labor from experienced employees which costs $75, and that on average, a farmer performs no more five missions per month. The five missions limit is a reasonable assumption because a field does not need to be scanned for nitrogen streaking or infestation every week, once a month will suffice. So, with this established, the costs to the company will be $375 in labor per month, making the monthly price for the service $468.75. Such a monthly bill may seem expensive at first, but because all of these analyses provide useful data to help improve crop yield, the service actually pays for itself and then some. For example, the UAS can scan for pests which have been shown to destroy 15%-47% of crops, depending on the study. However, with the expert advice from the agricultural advisers, this number will be greatly reduced to an estimate 5%, thus increasing the profit that the farmer will make. What really sets the Andover Blueprints' solution apart from the competition is that it is not just a UAV with a sensor strapped to it. The team has designed a comprehensive solution for the customer. Employees will analyze data collected by the UAV and will guide the farmer to make the best decisions making the UAV a fantastic catalyst for their business. To provide this service our expert employees will utilize machine learning algorithms and other features such as daily weather reports and the time in a crop's growth cycle to provide up to date real time data and the smartest advice for the customer to take the best decision for their interests/business. As previously mentioned in section 4.2, the upfront cost of this state-of-the-art data analysis service is much cheaper than its competitors. They can charge $525 or more for gathering data on an 100 acre field, whereas the team's UAS data analysis solution costs $56.25 less than that and allows farmers to choose what data they collect on their fields. Due to this and the fact that most farmers are not accustomed to doing complex data analysis themselves, the team expects nearly all customers to use the data analysis service provided. So, considering this and the fact that corn is only grown for 9 months in the year, the team believes each UAS will bring in an annual $4,218.75 of total revenue per drone with $843.75 of that being profit. Assuming that the team sells the same number of units as projected in section 4.2.1, the total revenue from the first year of data analysis will be $421,875.00 with a profit of $84,375.00. It should be noted that these number will increase as more units are sold and more customers join the service, eventually reaching a yearly revenue of $3,375,000.00 and a yearly profit of $843,750.00 after 5 years.

## 4.5 Additional Commercial Applications

Other than agriculture, there are many markets where the Andover Blueprints' UAS is incredibly beneficial. Even though the Andover Blueprints' company is very focused with agriculture, these additional missions are necessary for its business because of the lack of agricultural revenue during the New England winter. The strength of the UAS the team has created is that it is exceptionally versatile. This advantage sets this UAS apart from the competition on the market. It is incredibly useful in a real world scenario for an actual customer. The Sequoia sensor is used in almost all of the UAV's missions, allowing a customer to complete many diverse objectives without changing the sensor. The Sequoia multispectral sensor is incredibly powerful because of its five lenses (red, green, NiR, RedEdge, and visual spectrum) and its sunlight sensor which ensures impeccable accuracy when measuring reflected light. It can be utilized in hundreds of missions ranging from agriculture to renewable energy. For example, the UAS's wide sensor array makes it great for geographical survey missions. A combination of green, red, and NIR filters allow for imaging natural vegetation, surveillance of man-made objects, and even beneath the water. This expands the consumer market for the product to large data companies, such as Landpoint, that collect and process the relevant data of the land to determine where and how they should be working both in urban and undeveloped areas. Also, as previously noted, the UAV's Sequoia sensor is able to monitor man-made objects, including electrical lines, oil pipelines, and solar farms. This can in turn help construction companies spot defects with buildings that are viable to collapse. Not only that, but the UAS can even aid corporations like National Grid in preemptively spotting structural problems in their electrical lines and fixing them before they cause a loss of power. The same goes for large oil companies that do not want to lose their cargo because of pipeline leaks or even full on oil spills. In the unfortunate event that an oil spill or another type of pollution begins to spread, the Sequoia's ability to detect disturbances both on land and water can assist environmental agencies in determining a strategy to quarantine the spill zone. Additionally, the drone's sensor can be used to find invasive species of algae and gives local environmental agencies an idea of how to restore the ecosystem to its most natural state. With the GoPro HERO5 Session on the UAV, the team's drone can also work for industries such as law enforcement by performing routine surveillance missions on city streets, thus allowing on duty cops to spend their time elsewhere. For more suburban or rural areas, local governments can use drones to determine the ice thickness on lakes and ponds to see if it is safe for ice skating.

One final non-agricultural use of the UAS would be for the U.S. military. The military is one of the largest UAS consumers in the market, making it an ideal business partner. The team's UAS will be able to perform reconnaissance missions using its multispectral sensor, as well as deliver payloads to various destinations as needed, using the UAS's internal GPS. None of these stated applications require any changes to the original drone's sensor array or physical aspects, which makes entering these markets highly feasible for the team.

Because the team did not want to waste money paying for extra abilities that would be illegal to the common consumer, even without the FAA regulations, the drone's capabilities would be the same. For example, the UAV cannot fly much faster than 87 knots. This is due to the fact that when the team decided on a engine, it chose one that was as cost effective as possible, instead of spending extra money to have the drone's max speed be higher than the legal limit. This lack of necessity to alter the UAS holds true even in foreign markets as well, because the U.S. is spearheading the drone regulation initiative. As a result, foreign countries have relatively light regulations placed on unmanned aircrafts, so it is easy to sell drones globally. In fact, the only main difference between the U.S.'s drone policies and those of other countries is how to actually get the pilot's permit. For example, if the drones were to be sold in Canada, owners of the team's UAS need to apply for a Special Flight Operations Certificate (SFOC), but in countries like China, no such certification is required. Other countries like India simply restrict UAS operations over public places, with few regulations about how they are flown in private airspace. To ensure that every customer can obtain his or her permit if necessary, safety trainers will be trained for the regulations of their country of operation, so that the team's company can easily expand into other markets as needed. In addition to this, the team's product will be able to be modified with package options that provide sensors or functions that add whole new worlds of functionality.

# Chapter 5

# Conclusion

Following months of meetings, reiterations, and teamwork, the Andover Blueprints completed an engineering design notebook that thoroughly documents the plan for the creation of a multi-use UAS for farming and other applications, as well as an elaborate business case and extensive services supporting the product.

The team recognized that each mission was designed to test the UAS's capabilities in a different manner. The logistics mission tests payload capacity, the survey mission tests endurance, and the dash mission tests speed. With this in mind, the team crafted solutions for each mission that maximized these values so that the final product was as versatile as possible, in order to give farmers the most use for their investment.

The logistics, survey, and dash missions bring CPI motors to farmers in the field, scan for crop health, and scan for nitrogen streaking respectively. After the team brainstormed the concepts for these and 13 other missions, it considered and calculated flight speed, height, route, and time taken. Through careful deliberation and computation, the team found the quantity and weight of fuel needed for the UAV to finish the missions and how wide the UAV's turns needed to be. Throughout this process, the team adhered to FAA regulations and economic restrictions to make the UAS legal and affordable to potential consumers.

Although the team felt that the objective function was only a partial measure of success, the members worked hard to maximize values in order to prove that the challenge statement was fully understood and addressed. For the logistics mission, the key objective function value was the payload weight. This shows that the challenge is emphasizing the value of being able to transport a large payload for the farmer. When designing the UAV to conduct the survey mission, the team worked to increase the endurance. The flight time was the main variable in the survey mission objective function, indicating that the purpose of the mission was to demonstrate the time aloft that the UAV could withstand. For the dash mission, the cruise velocity of the aircraft had a significant effect on the mission objective function. This indicates that maximizing the speed of aircraft on this mission produces a stronger solution and therefore a stronger multiuse UAS for a farmer. The number of additional missions has the potential to notably increase the additional missions objective function. It can be assumed that this indicates that increasing the variability of the UAS increases its helpfulness to a farmer and is therefore a better solution. With this in mind, the team worked to increase the number of additional missions that the drone could create. Finally, the average percent profit that the team hypothetically makes on the services and products offered is the single-most effective value to increase the objective function for the business case. This indicates that the competition values this aspect of the business case, so increasing it allows the UAS to be a better product. However, the competition limited this value to 25%; therefore, the possible objective function for the business case is limited to 0.20. In essence, the objective function allowed the team to quantify the effectiveness of the solution and better understand the purpose of the challenge.

The final objective function value was 0.7536. The team's other values for the function were 1.000 for the dash speed, 0.8973 for the survey time, 0.8513 for the additional missions, 0.8196 for the logistics weight, and 0.2000 for the business profitability.

All in all, this competition shined a light on the detail required to create a feasible tech startup and equipped the team members with skills they will carry on in their STEM careers. The Andover Blueprints are grateful to RWDC for providing a program that has inspired them to continue being intrigued by engineering and design.

Here is the link to the team's citations: http://bit.ly/2oyYjLx